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Design of a wearable device to detect the psychological state of an athlete to ensure the best performance: An example in Rugby

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Júlia F.

Abstract

The continuous professionalization of sport and the technological improvement makes that athletes and coaches have a lot of tools for train and improve the performance and technical skills. Sports psychology is an important part of the training, it uses knowledge and skills to address optimal performance and well-being of athletes.
The continuous evolution of technology, especially in the field of electronics and its miniaturisation, and the consequent drop in sensors' price has sparked the tremendous diffusion of wearable devices that we witness today. The use of physiological signals in sport is gaining importance. This kind of wearable devices can be used to report the physiological and psychological state of the athletes and this information can be used for achieve better results in performance and improve the weakness.
The aim of this project is build a device, by using Bitalino a new biomedical sensor equipment toolkit, which allows to detect the psychological state of the athletes in pre performance moment. The device is used in order to achieve the best psychological state of the athlete to improve performance results. The device is controlled with an application done with MATLAB.

Estratto

La continua professionalizzazione dello sport e il miglioramento tecnologico fanno sì che gli atleti e gli allenatori dispongano di molti strumenti per allenarsi e migliorare le performance e le capacità tecnica. La psicologia dello sport è una parte importante dell'allenamento, utilizza conoscenze e abilità per affrontare le prestazioni ottimali e il benessere degli atleti.

La continua evoluzione della tecnologia, specialmente nel campo dell'elettronica e della sua miniaturizzazione, e il conseguente calo del prezzo dei sensori ha spinto all'enorme diffusione dei dispositivi indossabili a cui assistiamo oggi. L'uso di segnali fisiologici nello sport sta guadagnando importanza. Questo tipo di dispositivi indossabili può essere utilizzato per segnalare lo stato fisiologico e psicologico degli atleti e queste informazioni possono essere utilizzate per ottenere risultati migliori nelle prestazioni.

Lo scopo di questo progetto è progettare un dispositivo, utilizzando Bitalino, un nuovo kit di strumenti per sensori biomedici, che consenta di rilevare lo stato psicologico degli atleti in un momento pre-prestazione. Il dispositivo viene utilizzato per raggiungere il miglior stato psicologico dell'atleta per migliorare i risultati delle prestazioni. Il dispositivo è controllato con un'applicazione eseguita con MATLAB.

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Acronyms

ARAS Ascending Reticular Activating System

BFB Biofeedback

CDA Continuous Decomposition Analysis

ECG Electrocardiogram
EDA Electrodermal Activity
EEG Electroencefalogram
ER-SCR Event-related Skin Conductance Reaction

GSR Galvanic Skin Response

HR Heart Rate
HRV Heart Rate Variability

IAPS International Affective Picture System
IAPZ Individual Affect-related Performance Zones
IBI Interbeat Interval
IRT Infrared thermography
IZOF Individual Zones of Optima Functioning

LPF Low Pass Filter

NF Neurofeedback
NN Normal to Normal
NN50 number of adjacent NN intervals that differ from each other by more

than 50ms
NS-SCR Non-Specific Skin Conductance Reaction

OLR Logistic Ordinal Regression

pNN50 percentage of NN50
PST Psychological Skills Training

RMSSD The root mean square of successive differences between normal heartbeats
RR Respiration Rate

SC Skin Conductance
SCL Skin Conductance Level
SCR Skin Conductance Reaction
SDANN The standard deviation of the average normal-to-normal
SDNN standard deviation of the IBI of normal sinus beats
SDNNI SDNN Index
SDRR The standard deviation of the IBIs for all sinus beats
SVM Support Vector Machine (SVM)

TF Transfer Function

UES Unió Esportiva Santboiana

W5SA Wingate Five-Step Approach

Chapter 1

Introduction

Biofeedback is the provision of information regarding one's own biological functioning, its main goal the development of self-regulation. Biofeedback consists of training individuals, through the use of instruments to change various physiological states (e.g., heart rate, muscle tension, brain activity). Through the course of such training, the idea is to get the individual to regulate desired changes without instrumentation. While biofeedback has been used in the treatment of health-related disorders, it has also been used in performance-related areas as well. As such, biofeedback has been investigated in conjunction with human performance, specifically sport and exercise performance. If, through biofeedback training, individuals could learn to perform at higher levels or exercise more efficiently, biofeedback would certainly be a valuable tool in sport and exercise [54]. Biofeedback is becoming a very important tool used in sports to improve the performance of the athletes.

Shaun M. Galloway investigated the effectiveness of biofeedback training on the accuracy of tennis serving. The participants were six male junior national elite tennis athletes. The results showed that the biofeedback training was effective in improving tennis serve accuracy. Social validation results indicated that the participants' mental skills adherence was improved and that the athletes were content with their serving accuracy results [24]. In 2019, Perry et al. used the Heart Rate Variability (HRV) technology, which enables practitioners to analyze the physiological effects of stress [32]. High levels of HRV are associated with improved stress management and sport performance. This study examined the effectiveness of 20 collegiate male soccer players existing mental strategies in maintaining high HRV following three separate stressors. Formenti and Merla, in 2017, used the Infrared thermography (IRT) a promising methodology in the field of psychophysiology [12]. An assessment of emotional states and computational psychophysiology through thermal infrared imaging in sport and exercise was done. Youngsook et al., developed a real-time neurofeedback system for psychological self-regulation of shooters using EEG wave. Based on the results of this study, neurofeedback system can apply various sports and contribute to help athletes' self-regulation and athletic performance enhancement in sport field [8].

Biofeedback can be used to analyse the psychological and mental state of an athlete. Mental and emotional components of behavior play an important role in the determination of human performance in sporting competition scenario. Studies have shown that mental readiness was felt to be the most significant statistical link with Olympics ranking [1].
Stress is defined as a physical, mental or emotional, demand, which tends to disturb the homeostasis of the body. Stress is inevitable in life and sport, and all performing actors, artists and athletes perform their tasks with varying stress levels. Used rather loosely, the term may relate to any kind of pressure, be it due to one's job, school work, marriage, illness or death of a loved one. The common denominator in all of these is change. Loss of familiarity breeds this anxiety with any change being viewed as a "threat".

Sports performance is not simply a product of physiology (for example stress and fitness) and biomechanical (for example technique factors) but psychological factors also play a crucial role in determining performance. However, every athlete has a certain stress level that is needed to optimize his or her game [33]. This level depends on factors such as past experiences, coping responses and genetics. Stress during sports, as in anything else in life, may be acute, episodic or chronic. For the most part in sports, it is episodic, whether during a competitive match between friends, or a championship game. While acute stress may actually act as a challenge, if not harnessed, it can evolve not only an episodic stressor that can affect one in the long term, but can also hamper one's play. It has been commonly suggested that the consistency in behavior, of these routines are closely related to overall performance quality [10, 39].

The relationship between stress and performance has been portrayed by the stress response curve created by Nixon P. in 1979. To better understand the effects of stress to performance, a graph in Fig. 1.1. of the stress performance curve was created explaining how stress affects performance in theoretical terms [18] .

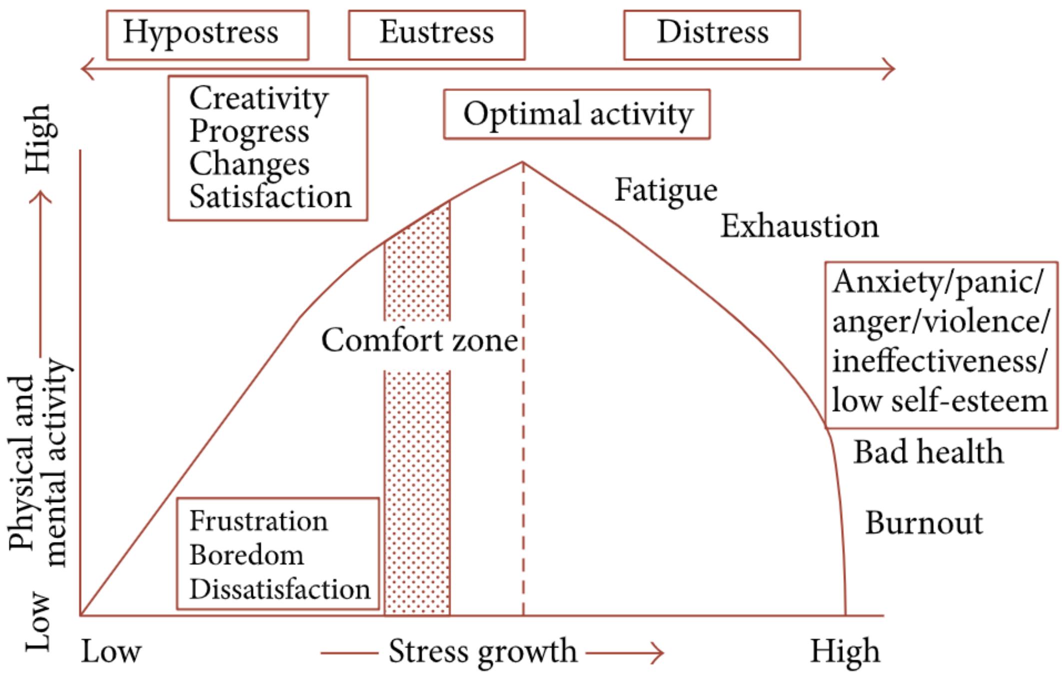

Figure 1.1: Human response to stress curve (according to Nixon P: Practitioner 1979, Yerkes RM, Dodson JD [18].)

The curve shows that as the level of stress increases, the performance level also increases, to the point of eustress, or healthy tension. Near the point of fatigue, an identified area called the Comfort Zone indicates the range of stress levels that we can absolutely manage and facilitates good performance levels. As stress begins to be perceived as overwhelming or excessive, the person reaches a fatigue point wherein the performance levels starts to decline. The ultimate end of overwhelming stress, called burnout, can be exhaustion or breakdown.

Stress is an inevitable part of athletes' life. The intense pressure of achieving high performances, maintaining a social life, dealing with financial obligations while away from family home present challenges that athletes must deal with every day. This puts a huge amount of pressure on doing always a good performances during the season. Timely recognition of stress can be helpful to individuals by providing them with different stress-coping mechanisms. Wearable sensors allow for real-time monitoring of athletes physiological signals that can be closely related to stress.

Arousal is the key issue in sport psychology. Specifically, physical and technical performance depends on the level of performer's arousal. However, arousal is determined by psychological processes such as emotions, which, in turn, depend on higher cognitive functions like thoughts. Arousal reflects general physical and psychological activity.
Arousal is the physiological and psychological state of being awoken or of sense organs stimulated to a point of perception. Heart rate is considered as one arousal measure.

In sport setting, arousal is often linked to anxiety. Anxiety is a negative emotional state with feelings of worry, nervousness and apprehension that is associated with the arousal and activation of the nervous system. In general, arousal has two kinds of effects on performance. First, it increases muscle tension and affects coordination. Too much tension is detrimental to performance. Second, arousal affects attention. Therefore, attention can become either too narrow with too much arousal, or too broad with too little arousal which makes person to pay too much attention to his/her environment. There are several theories as to how arousal affects performance.

Inverted U hypothesis by Yerkes and Dodson proposes a relationship between arousal and performance in a symmetrical inverted U. Increases in arousal will result in the increase of performance, up to a point (optimal arousal) beyond which further arousal is dysfunctional to the outcome of performance.
Individual Zones of Optimal Functioning (IZOF) takes into account that people have different levels of anxiety and arousal that are unique in making

them perform at their best. Some people perform their best with low anxiety, some with a medium amount and others with a high amount. The amount of anxiety/arousal that an individual requires to perform their best is based on individual characteristics [61].
Several arousal theories aimed to address optimal levels for specific kinds of sports. The 'Inverted U theory' by Yerkes and Dodson, states that too high or too low levels of arousal and anxiety cause a person to perform poorer compared with performance at a medium level of arousal. But opinions still differ concerning the optimal zone of arousal. Perkins et al. claim that the motivational state determines if high levels of arousal strengthens or weaken performance in motor tasks. This theory is most accepted nowadays. Optimal arousal models contend that high arousal contributes to inhibited athletic performance, whereas there is reversal theory research which indicates that high positive arousal may enhance performance [44].

Given the long history of arousal in psychological theory, it would seem that the measurement of arousal would be straightforward. Unfortunately, this is not the case. Rather, the failure of different measures of arousal to agree with each other is perhaps the greatest source of dissatisfaction with the use of arousal as a unifying theoretical construct. Some of the sources of the controversy surrounding the use of arousal as a psychological construct include debates about broad issues in measurement, the importance of individual differences, the level of inference between the measure and the construct, and the effect of various situational manipulations.

A common, simple and noninvasive method to assess the arousal is to analyse the power spectral analysis of the Heart Rate Variability (HRV). HRV is the study of the differences between consecutive heart beat, obtained from the time series of beat-to-beat intervals from an electrocardiogram (ECG) between consecutive heart beats. HRV is a useful index for assessing human emotion since it reflects the autonomic nervous system, studies have investigated the validity [27, 2, 43, 9].

Another way to measure different levels of arousal is skin conductance from EDA. Electrodermal activity refers to changes in the skin conductance

at the skins surface. These changes are an indirect indicator of activity in the sympathetic branch of the autonomous nervous system and used in various clinical and nonclinical settings. EDA can be measured as a result of eccrine sweat gland activity [58].
Activity of the sympathetic branch is associated with emotion, cognition and attention. Therefore conditions such as anxiety, high physical arousal or high cognitive work load can increase the sympathetic tonus and change the peaks of the EDA. This physiological measure could give a more detailed, event related and specific insight into arousal patterns during actual performance.

Nowadays, in sports market, there are a lot of devices monitoring the constants and the movements of the athletes (Fig. 1.2). These devices go from the most commercial ones which are able to track your sport activities, and HR (Heart Rate) to the most specified ones which are developed for specific trainings and sports. Other devices are able to track the movements of the athletes in order to post analyse them and find where the techniques can be improved to get the best performance.

The aim of this project is to build a device which is able to find and measure the best psychological state of the player for execute important actions. With this device the athlete will be notified by a stimuli when he/she achieves his/her best psychological state for achieving the best performance.

To get the final device several steps have to be done in order to achieve the most effective and efficient result. The steps are the following ones:

- Baseline acquisition. In this part of the project the aim is to get the EDA (Electrodermal Activity) and the HRV (Heart Rate Variation) of the athlete when he/she is calm down without stress. This is useful to get her normal state and the arousal when he/she is calm down.
- Find his/her zone of optimal performance. Each person has a zone of optimal performance which can be equal to the one of other person or not. This zone can be found by measuring the arousal when the person is performing, looking to the results obtained and classificate the biosignals according to the results.

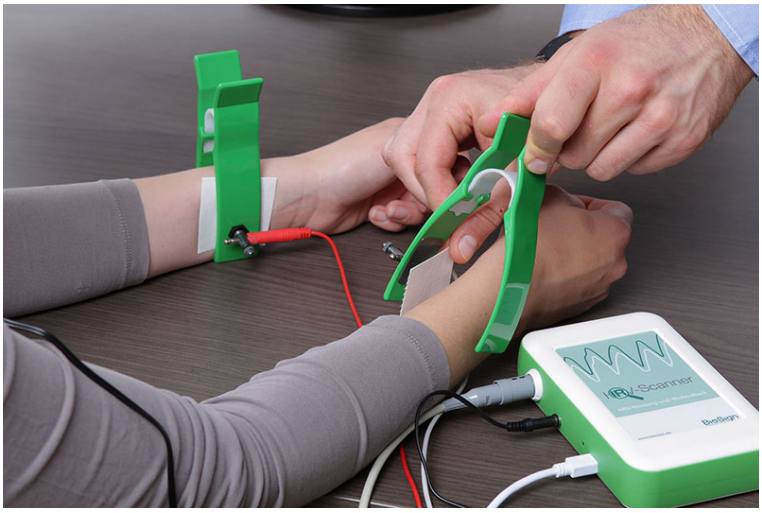

Figure 1.2: Device used for acquiring biosingals

- Finally, test the device with the athletes, performing when the device detects that they are in their zone of optimal performance

This thesis is divided in 7 chapters. The initial part the state of art and introduction are presented. Then, the explanation of how the system has been developed. Finally, to conclude the test that was done in order to rate the effectiveness of the device, results, conclusions and future work:

- Chapter 1: Introduction, the project is presented and the actual situation of the knowledge that will be used to achieve the wanted result. The biofeedback and the use of psychology in sport and the results that they are achieving in this moment.

- Chapter 2: Psychology in Sport, a state of art of the subject is presented. The hypothesis that will be used to understand how can be used and applied to the propose of the work.

- Chapter 3: Biofeedback, brief presentation of it and state of the art in sports. In this chapter the biosignals selected for the work are explained and justified: The results that they can give and the information that can be obtained from them. The features selected in order to better compute and understand the psychological state of the athlete.

- Chapter 4: System Development. The chapter explains all the steps followed to arrange the device, the software and hardware part. The components used to build the hardware part and machine learning tools. The graphic interface is also shown in this part.

- Chapter 5. Device Testing: In order to check the effectivity and the working system test in field are performed. All the tests parts are described, such as the participants, setup, procedure, etc. These tests are used in order to understand the work and the weakness of the system.

- Chapter 6: Results and discussion, the results of the test comparing different ways of performance and the results of the survey that the athletes answered.:

- Chapter 7: Conclusions and future work.

Chapter 2

Psychology in sport

Sport psychology is an interdisciplinary science that draws on knowledge from many related fields including biomechanics, physiology, kinesiology and psychology. It involves the study of how psychological factors affect performance and how participation in sport and exercise affect psychological and physical factors [58].

Even after considerable years of experience, athletes will continue to make errors in execution of athletic skills. There are many reasons why errors are repeated. Persistent errors made by beginning athletes might be due to imitation of other athletes who are making the same errors; lack of focus; and accidental positive reinforcement, etc. These errors can be corrected, not only by training many times the skill, by identifying the error and apply correct behavior instruction.

The effectiveness of psychological skills training (PST) on performance has been tested in sport psychology reviews. This is especially true for those working with elite athletes, The intended purpose of these PST programs is to provide athletes and teams with the skills and strategies to overcome cognitive and emotional barriers, in the service of achieving their goals [59, 4].

Striving for success in practice and competition can be really struggling for athletes. It is not easy for them to attain excellent results during important events, especially when extended over long periods. In these situations, sport psychologists can help athletes prevent underperformance and/or find other ways to reach and maintain peak performance (i.e., optimal or outstanding achievements). Peak performance is an umbrella term used to classify positive states surrounding performance, which includes concepts such as peak experience [47].

2.1 Arousal

Arousal is the physiological and psychological state of being awoken or of sense organs stimulated to a point of perception. It involves activation of the ascending reticular activating system (ARAS) in the brain, which mediates wakefulness, the autonomic nervous system, and the endocrine system, leading to increased heart rate and blood pressure and a condition of sensory alertness, mobility, and readiness to respond. Arousal is a state in which you feel excited or very alert, for example as a result of fear, stress, or anger [46].

Arousal is important in regulating consciousness, attention, alertness, and information processing. It is crucial for motivating certain behaviours, such as mobility, the pursuit of nutrition, the fight-or-flight response and sexual activity (the arousal phase of Masters and Johnson's human sexual response cycle). It is also important in emotion and has been included in theories such as the James-Lange theory of emotion. According to Hans Eysenck, differences in baseline arousal level lead people to be extraverts or introverts.

The Yerkes-Dodson law states that an optimal level of arousal for performance exists, and too little or too much arousal can adversely affect task performance.

Arousal is the key issue in sport psychology. Specifically, physical and technical performance depends on the level of performer's arousal. It reflects general physical and psychological activity.

2.2 The inverted U hypothesis and optimal arousal

The inverted-U relationship was first identified by Yerkes and Dodson (1908) using rats and mice in laboratory experiments. The Yerkes–Dodson law is an empirical relationship between arousal and performance, originally devel-

oped by psychologists Robert M. Yerkes and John Dillingham Dodson in 1908 [18]. The law dictates that performance increases with physiological or mental arousal, but only up to a point. When levels of arousal become too high, performance decreases. The process is often illustrated graphically as a bell-shaped curve which increases and then decreases with higher levels of arousal. They found that there was a curvilinear relationship (inverted-U shape) between motivational level (arousal) and performance.
The studies from other psychologists Lindsey, Hebb and Malmo tried to establish the optimal levels of arousal for performance [55, 30, 40]. They did the basis of the optimal arousal theory, which explain that up to a certain point, the known as the optimal point, the performance level of the subject improved as the arousal level increased. Any further increase in arousal once this point had been reached would result in a deterioration of performance. Consequently, a graph of performance against arousal would take on an inverted-U shape, as shown in Fig.2.1).

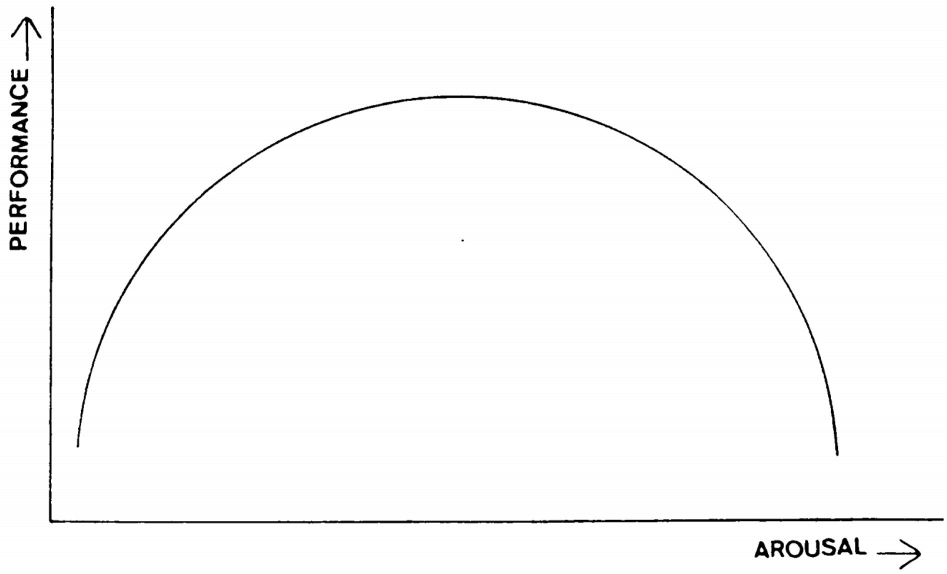

Figure 2.1: Relationship of level of performance to level of arousal according to the inverted-U hypothesis [20].

2.3 Optimal arousal and sports performance

The optimal arousal theory is applied to sport it is considered the optimal point, which is the point of interaction between the arousal and performance and it is supposed to be the one where the performance is maximised. There are simple generalitsations about the level of arousal required for different motor tasks quoted in the sports psychology literature listed below:

- A high level of arousal is essential for optimal performance in gross motor activities involving strength, endurance and speed.
- A high level of arousal interferes with performance involving complex skills, fine muscle movements, coordination, steadiness and general concentration. slightly above average level of arousal is preferable to a normal or subnormal arousal state for all motor tasks.

The general consensus has been that if arousal levels are too high or too low, in order to maximise performance, arousal must be increased or decreased to some "intermediate", optimal level. Martens (1974) stated [41]:

"Greater physical energy requirements combined with increasing task difficulty reduce the range of optimal arousal even further. High energy requirements with high task difficulty are the precise task conditions that exist in many well known sports such as tennis, basketball and wrestling. Thus, because these activities have such a narrow range for optimal performance, it is easy to understand why it is so difficult to achieve and maintain an optimal arousal level when performing these tasks. "

Various examples are provided by a field research study undertaken by Klavora (1978), Weinberg and Genuchi (1980) and Ebbeck and Weiss (1988) [36, 60, 19]. They used different athletes, basketball players (n=145), golf players (n=63) and track and field athletes (n= 51) were the subjects of study. The arousal levels of players prior to games were measured and also subjective evaluations of each player's performance in relation to the player's performance ability were provided. When the players' arousal levels prior to the game were plotted graphically against their basketball performance scores, bell-shaped curves supporting the Inverted-U relationship were obtained. Klavora claims that players were found to be performing poorly because they were either under or overaroused, a finding which is not unusual in studies of this type. The position of the "bell-shape" along the pre-game arousal axis was found to vary and two distinct groups were found. This led to Klavora to conclude, based on the inverted-U hypothesis paradigm, that both groups required additional arousal prior to games, albeit to a different degree. Klavora also claimed to be able to identify a "customary level of arousal", recognisable as a range of scores on an arousal continuum for each athlete.

2.4 Individual Zones of Optimal Functioning and Individual affect-related performance zones

The most popular account for the relationship between arousal and performance is the model of Individual Zones of Optimal Functioning (IZOF) [28]. IZOF proposes that there are individual differences in the way people react to anxiety. Some tend to succeed when anxiety is low while others tend to succeed when anxiety is high. The Individual Zone of Optimal Functioning (IZOF) model is both a theoretical framework and a practical approach that enables qualitative and quantitative analysis of the functional relationship between emotions and performance. IZOF model is a sport-specific framework that describes the relationship between emotional experiences and relative success in sporting tasks on the basis of individual rather than group-based pattern [48].

Therefore each person has his/her own preferred level of anxiety that allows them to perform at their optimum. When athletes are in their optimal performance zone this means that they are in they preferred level of anxiety. If an athlete experiences too much or too little anxiety, this can hinder performance, as the athlete is out of his/her optimal zone Fig.2.2).

In addition to anxiety, IZOF allows for a description of a variety of emotional states which could be either helpful or unhelpful. While in older explanations emotions were called either positive or negative, Hanin suggested that in sport setting it is more useful to distinguish between helpful and unhelpful

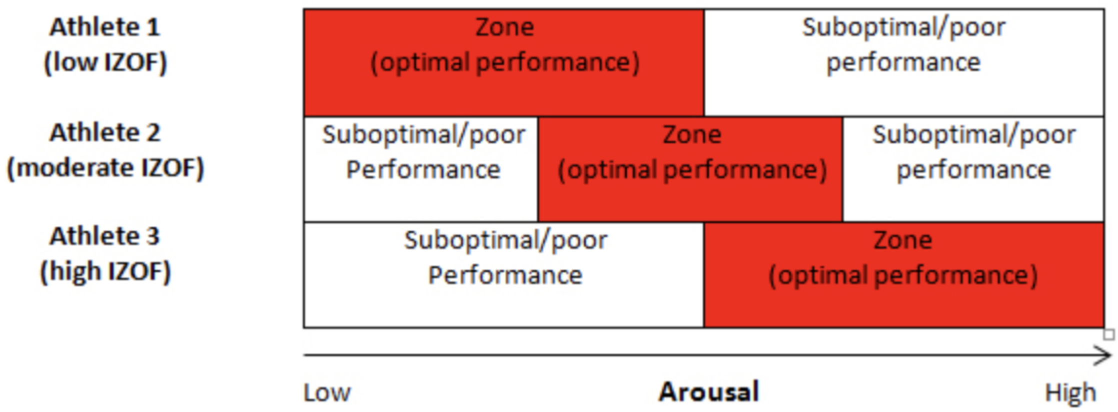

Figure 2.2: IZOF theory illustrated [20].

or optimal and dysfunctional emotions. For example, some athletes may notice that feeling excited is not conductive to performing well, while others would say that feeling angry helps them to reach their optimal performance state. Thus, the Individual Zones of Optimal Functioning model suggests that each athlete could find out his or her optimal combination of useful emotions and learn, how to reach this unique state prior to competitions [20].

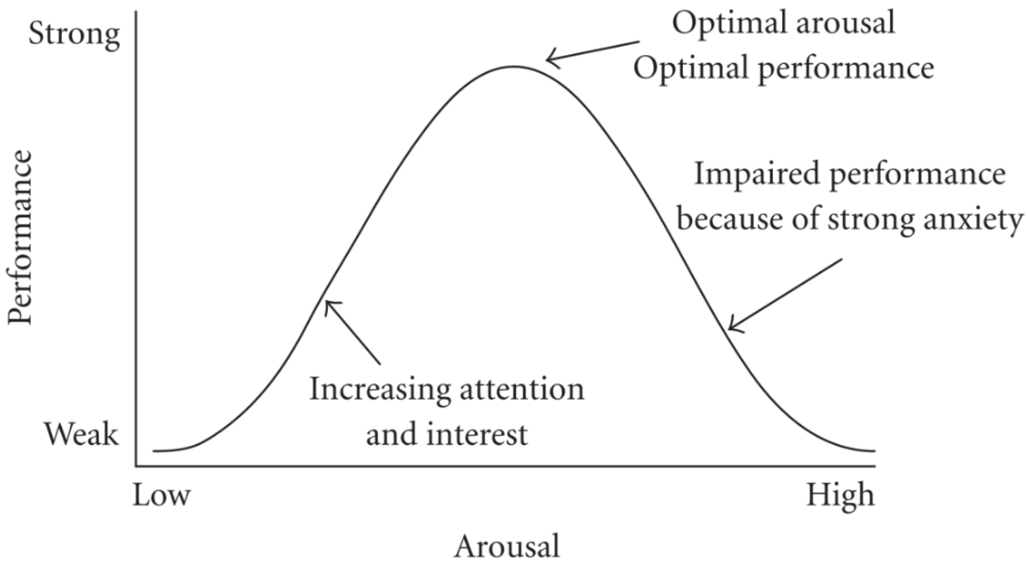

Figure 2.3: Bell shaped theory [20].

The main criticism of the Individual Zones of Optimal Functioning model is that it does not explain why some people perform better when in certain

emotional states and others do not. Still, IZOF is a useful model that helps to improve athlete's self-awareness and psychological readiness. A common way to find out the individual optimal performance zone is individualized emotion profiling.
The IZOF aims to predict the quality of upcoming performance with respect to the current or anticipated pre-performance emotional state of the performer. According to Hanin, the IZOF attempts to distinguish between poor and optimal performance based on documented emotional experiences associated with performance quality in a certain period of the performer's career. The IZOF model primarily emphasizes the within-individual dynamics of subjective emotional experiences associated with performance qualities, so that emotions patterns of successful performances can be distinguished from the emotional patterns of less successful performances in each performer. Methodologically, individually optimal (and dysfunctional) zones serve as empirically established criteria of an optimal performance state reflecting an individual's performance history.

Despite these principal contributions, the IZOF model has limitations. IZOF-based analyses typically produce profiles with two zones that describe the feeling intensity associated with best and worst performance levels referred to as the "in-out of the zone" principle. Though the IZOF model describes performance outcomes as probabilistic rather than absolute, studies rarely estimate the likelihood of each performance outcome across feeling intensity. Furthermore, the model does not account for moderate performances, undefined gaps between good- and poor-zones, and overlaps between zones (where both good and poor performance zones overlap at a certain level of intensity). The objective of this study and of the pIZOF method (as one method in the array of IZOF-based methodologies) is to generate profiles that account for moderate performance levels, and describe the exact probability of poor, moderate, and good performance levels.

OLR (also referred to as Logistic Ordinal Regression) is a statistical procedure that estimates the probability of ordinal outcomes such as poor, average, and good performance levels. For the purpose of individualized performance profiling, OLR is used to estimate the probability of performance

levels across a range of feeling intensity [29]. OLR was introduced to the feeling-performance profiling literature by Kamata et al., and became the foundation for the individual affect-related performance zones (IAPZ) method. Though every study that has applied Kamata's probabilistic method has measured general dimensional affect rather than discrete feelings, OLR is not exclusive to the IAPZ method or to dimensional affect: OLR could be applied to discrete feelings in the IZOF model. IAPZs are defined by Johnson, Edmonds, Moraes, Medeiros Filho, and Tenenbaum "as that range of affective intensity or heart rate within which an individual has the highest probability of performing at a specific performance level (e.g., poorly, moderately, or optimally)" [22].
Tenenbaum, IAPZs consist of the reciprocal relationship between the perceived intensity of an affective state and the quality of an ensuing performance". The IAPZ method is, therefore, a process by which the idiosyncratic relationship between performance and the intensity of affect can be known and represented visually as an example Fig.2.4 from these results.

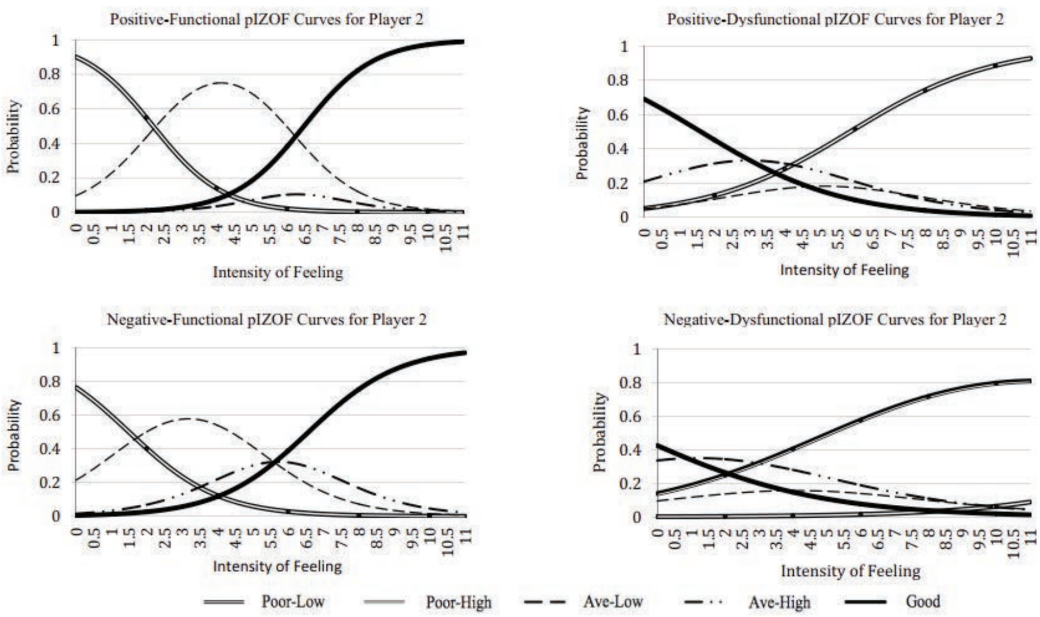

Figure 2.4: Profiles describing the probability of various performance levels across feeling intensity [56].

The probabilistic method developed by Kamata et al. has been applied to the IAPZ method, but has not been used to profile discrete feelings that are characteristic of the IZOF model. In 2015 Flett concluded that the IZOF model can incorporate OLR as a statistical tool to develop probabilistic profiles [56]. For simplicity in this thesis the IZOF model will be assumed.

Chapter 3

Biofeedback: ECG and EDA

Biofeedback is the process of getting information from many physiological functions using instruments which provide the activity of these signals, with the objective of being able to manipulate and get information from them. In biofeedback the physiological information is got by means of sensors connected to the body of the subject. The process of biofeedback is illustrated in Fig.3.1. It can be used to improve health, performance, and the physiological changes that often occur in conjunction with changes to thoughts, emotions, and behavior. Some of the processes that can be controlled include brainwaves, muscle tone, skin conductance, heart rate and pain perception [23].

The technology of biofeedback for sport psychology and specifically for psychological skills training is widely used with a great results. Psychological skills learned through biofeedback training can be applied in practice and competition and can lead to improved athletic performance. Sport achievement is the result of well-planned hard training with progressively growing demands and challenges over a long time period. The main goal of the training process is to increase the athlete's work capacity and skill capabilities as well as to develop strong psychological qualities for successful performance.

Biofeedback application originated from the field of psychophysiology at the end of the 1960s. Psychophysiology is defined as a "scientific study of the relationship between mental and behavior activities and bodily events. Therefore the relevance of biofeedback interventions to athletic preparation

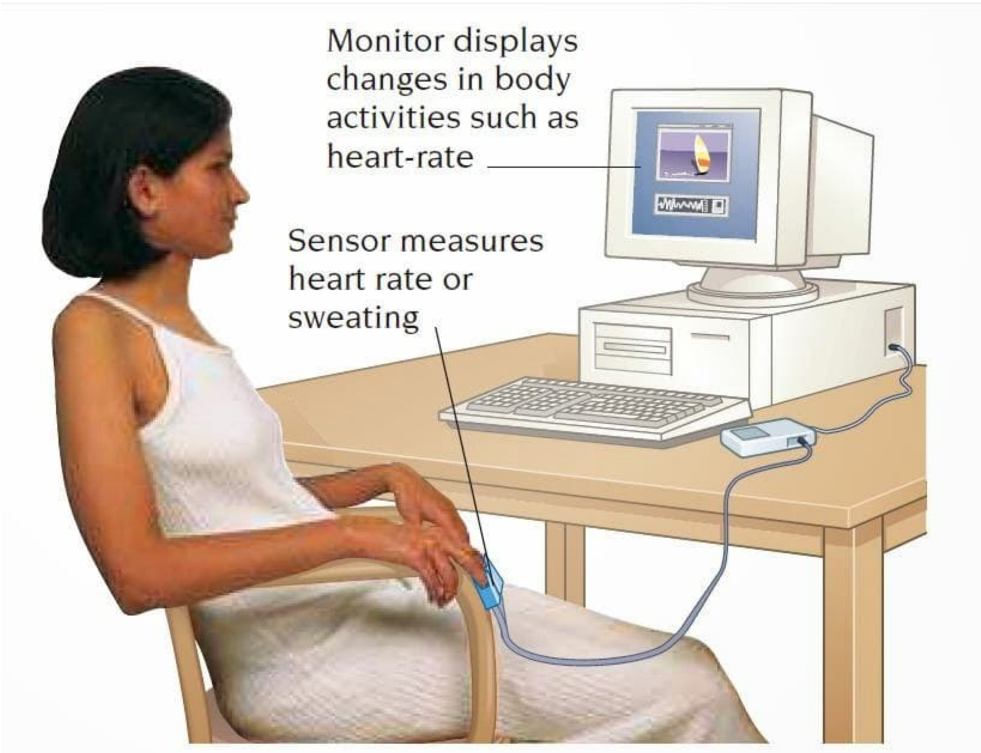

Figure 3.1: A diagram showing the feedback loop between person, sensor, and processor to help provide biofeedback training [25].

based on the psychophysiological principle presented by Green, and Walters (1970) is understandable. This principle states that every change in the physiological state is accompanied by a parallel change in the mental and emotional states and, conversely, every change in the mental and emotional states—conscious or unconscious—is accompanied by an appropriate change in the physiological state. Therefore, generally speaking, the biofeedback application can be presented as an application of psychophysiology in sport and exercise [23].

It is important to understand that although the terms biofeedback and biofeedback training are frequently used synonymously in the literature, they are two separate concepts. Biofeedback (BFB) is the use of special electronic devices with electrodes and sensors in order to assess, monitor, and feedback psychophysiological information to a person. The main idea of BFB is to provide the individual with information about his or her body's or mind's reactions to various situations. Today, owing to modern technology, it is possible to measure physiological indices—such as heart rate, muscular activity, brain wave activity, respiration, blood pressure, skin temperature and sweat gland activity—during real-time events. These physiological changes are presented to the athlete on a PC screen in a graphic or multimedia form and help regulate the mind and body according to the psychophysiological principle.

Biofeedback training is a technique of gaining control of self-regulation, based on information or feedback received from the athletes' body and mind. Following intensive BFB training, psychological skills become automatic reflexes. Various types of instrumentation (or BFB modalities) are used for physiological signal recording and are applied as the feedback. The modalities include the following measures:

- Muscle tension is measured by surface electromyography (sEMG feedback)
- The brain's electrical activity is measured by electroencephalography (EEG feedback), which has recently become known as neurofeedback (NF)
- The electrical activity of the skin surface (electrodermal activity, or EDA) is measured by skin resistance (historically known as the galvanic skin response, or GSR), by skin conductance (SC), and by skin potential (SP)
- Heart activity is measured by electrocardiography (heart rate feedback, or HR), the most recent form of which is heart rate variability (HRV), measured by interbeat interval (IBI)
- Blood pressure, measured by sphygmomanometry (blood pressure feedback, or BP); (6) the respiratory rate (RR) is measured by a strain-gauge device (R feedback)
- Thermal feedback (T) is measured by peripheral skin temperature, often referred to as temperature feedback.

The role of BFB training in athletic performance enhancement is presented in Fig.3.2.

As shown in Fig. 3.2, competitive stress (1) is usually accompanied by changes in physiological indices, such as increased heart rate, blood pressure, muscle tension, and respiration (2). Based on the psychophysiological principle, the physiological changes are linked to the state of the athlete's body and mind. The process of BFB training includes learning and improving self-monitoring and self-regulation skills with different BFB modalities (3). The final result is an improvement in the athlete's self-regulation skills, (4) which leads to performance enhancement (5) under competitive stress.

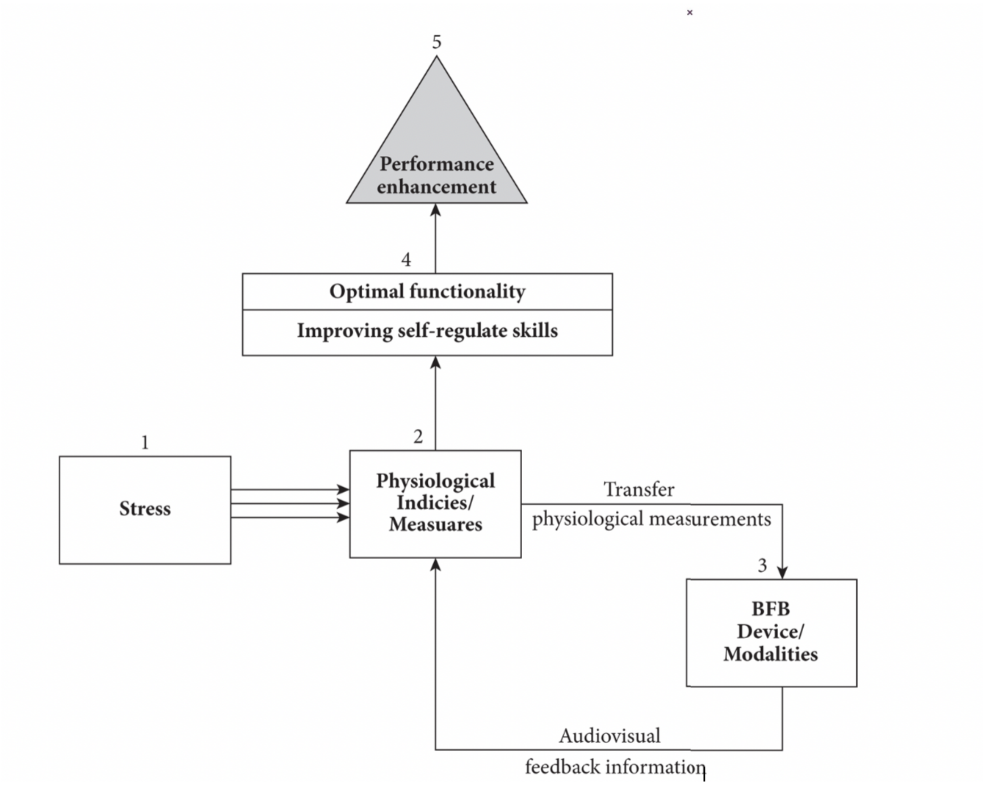

Figure 3.2: Biofeedback training and performance enhancement [5].

The Wingate Five-Step Approach (W5SA) is a self regulation technique incorporating BFB training. Its main aim is the development and the transfer of self-regulation skills from the laboratory to the training and competition setting. The W5SA is composed of a self-regulation test and five steps, in which the first three steps are provided in the laboratory and the last two steps are provided in training/competition settings (Fig. 3.3):

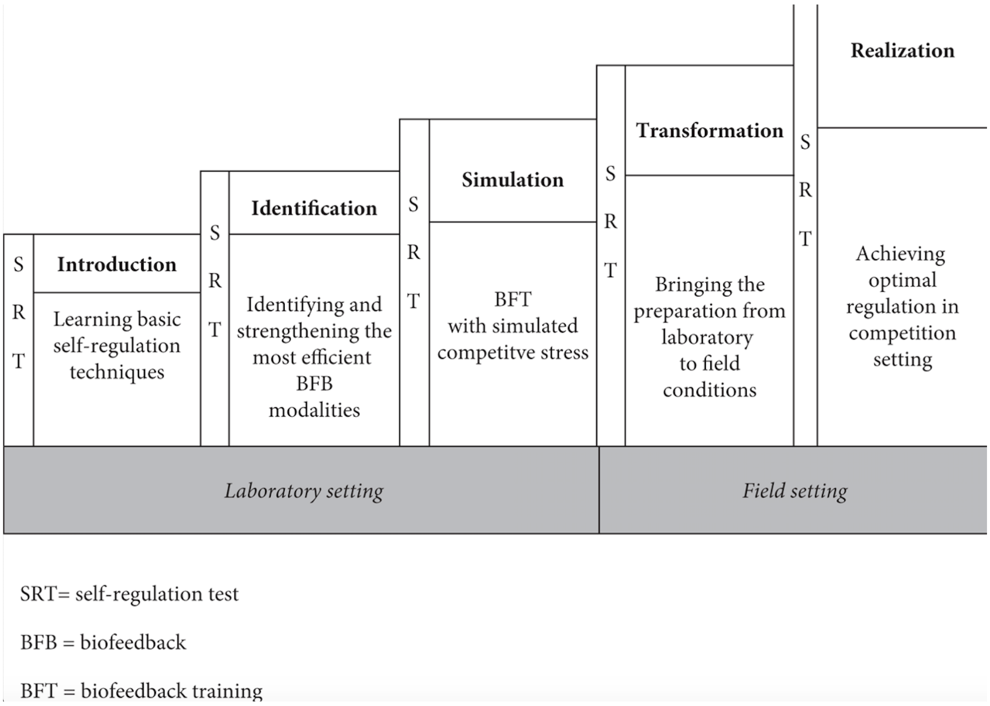

Figure 3.3: Schematic description of the Wingate Five-Step approach for mental training [5].

- Step 1. Introduction: This step focuses on learning basic self-regulation strategies/techniques, such as relaxation, imagery, concentration, self-talk, and BFB training. Practice takes place in the lab; the main goal is to achieve the ability to master relaxation-excitation waves. For example, the individual is asked to achieve relaxation with one of the BFB modalities for about 2 or 3 minutes, followed by deep relaxation for 5 to 10 minutes, and then excitation for about 2 to 3 minutes.

- Step 2. Identification: This step concentrates on identifying and strengthening the most efficient BFB response/modality, according to the sport discipline. Practice takes place in the lab, where the athlete is required to master the relaxation-excitation waves quickly, accurately, and reliably. In this step, relaxation/excitation speed and quality are highly important.

- Step 3. Simulation: This step provides BFB training with simulated competitive stress using audio/visual material. Practice takes place in the lab, where the athlete practices shifting from one mental state to another by observing films from competitions and listening to competitive noises specific to his or her sport discipline.

- Step 4. Transformation: This step focuses on transferring mental preparations from laboratory to the field using a portable BFB device. Practice takes place in an actual training setting, and in different locations such as before/after warm-up, games, races, and matches, as well as in the hotel, locker room, and bus.

- Step 5. Realization: This last step focuses on achieving optimal regulation in a competition setting. The athlete applies self-regulation skills in precompetitive activities and preperformance routines.

FB training has gone through many developments in the last decade. The application of this process in sport has been expanded from lab to field, from one BFB modality to packaging with other psychological interventions, and finally the integration of BFB training as part of athletic preparation. In recent years there has been an enormous interest in psychophysiology in sport, and particularly in BFB training.

The psychophysiological monitoring consists in the assessment of the activation and functioning level of the body. In sport, it can be used to better understand the underlying processes of performance and to subsequently increase or optimize it [47].

3.1 Electrodermal Activity

Electrodermal activity (EDA) refers to changes in the skin conductance at the skins surface. These changes are an indirect indicator of activity in the sympathetic branch of the autonomous nervous system and used in various clinical and nonclinical settings. EDA can be measured as a result of eccrine sweat gland activity [58]. Activity of the sympathetic branch is associated with emotion, cognition and attention [11]. Therefore conditions such as anxiety, high physical arousal or high cognitive work load can increase the sympathetic tonus and change the peaks of the EDA. This physiological measure could give a more detailed, event related and specific insight into arousal patterns during

actual performance. Arousal measures obtained by the means of EDA can give no specification of valance of a specific emotion.
The typical unit used for Electrodermal activity is μS.

There are two main components to the overall complex referred to as EDA. One component is the general tonic-level EDA which relates to the slower acting components and background characteristics of the signal (the overall level, slow climbing, slow declinations over time). The most common measure of this component is the Skin Conductance Level (SCL) and changes in the SCL are thought to reflect general changes in autonomic arousal. The other component is the phasic component and this refers to the faster changing elements of the signal - the Skin Conductance Response (SCR). It is important to be aware that the phasic SCR, which often receives the most interest, only makes up a small proportion of the overall EDA complex.

It is important to recognise that the tonic EDA (also known as the SCL) generates a constantly moving baseline. In other words, the background Tonic SCL is constantly changing within an individual, and can differ markedly between them. Simply averaging across the whole signal is inadequate as a measure of SCL because it likely to over-estimate the true-SCL as such averages will also contain SCRs (thus artificially elevating the measure). In addition, it is not clear if any given overall SCL measured in this way can be seen as being 'high' or 'low' for that individual. At the very least, the researcher should seek to subtract the amplitudes of SCRs from the Tonic signal before establishing a truer representation of background SCL, or take measurements from periods outside of SCRs in the signal.

The SCR is often referred to as a "peak" of activity as it appears as a rapid increase in the signal value. If the SCR appears in response to a stimulus (typically within 1-5 seconds), then it is referred to as an Event-Related SCR (ER-SCR), while if it appears without any discernible cause, it's referred to as a Non-Specific SCR (NS-SCR).

While the SCR is one component of the GSR activity, this only represents the fast-changing signal in response to a stimulus. The other component is the tonic, continuous, slowly-changing Skin Conductance Level (SCL).

A graphical representation of the components of an ER-SCR is provided in Fig. 3.4.

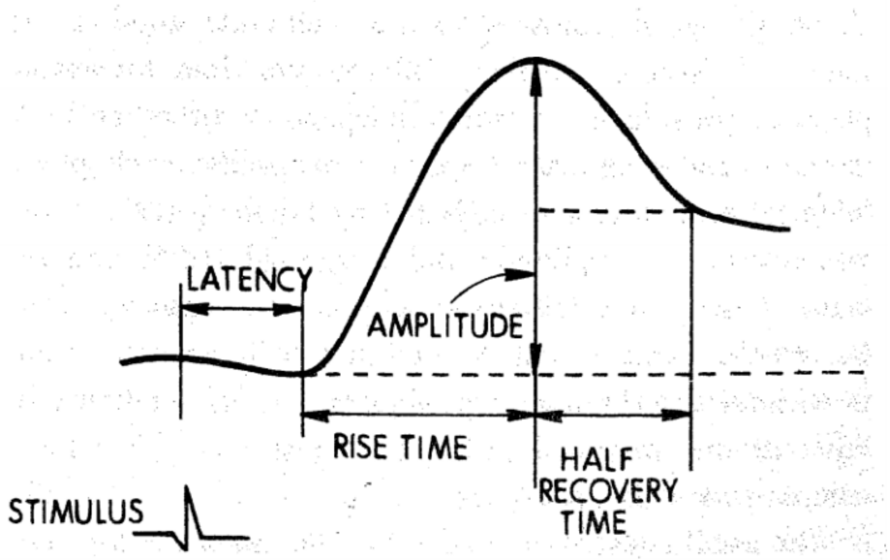

Figure 3.4: Graphical representation of principal EDA components [13]

EDA data has to be processed and filtered for later analysis. The best recommendation is to use a low pass filter settings of 0.12 Hz and high pass filter setting of 15 kHz [26, 6].

After filtering in order to find all EDA features a Continuous Decomposition Analysis will be done. It decomposes SC data into continuous tonic and phasic activity. This method is based on Standard Deconvolution, is comparatively fast and quite robust (artifacts). The number of significant SCR, the mean amplitude, the latency can be found [35].

3.2 Electrocardiography

Electrocardiography is the process of producing an electrocardiogram (ECG), a graph of voltage versus time of the electrical activity of the heart using electrodes placed on the skin. These electrodes detect the small electrical changes that are a consequence of cardiac muscle depolarization followed by repolarization during each cardiac cycle (heartbeat).

The ECG records the electrical activity of the heart, where each heart beat is displayed as a series of electrical waves characterized by peaks and valleys. Any ECG gives two kinds of information. One, the duration of the electrical wave crossing the heart which in turn decides whether the electrical activity is normal or slow or irregular and the second is the amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked [50].
Normally, the frequency range of an ECG signal is of 0.05–100 Hz and its dynamic range – of 1–10 mV. The ECG signal is characterized by five peaks and valleys labelled by the letters P, Q, R, S, T, the normal wave form is represented in Fig. 3.5.

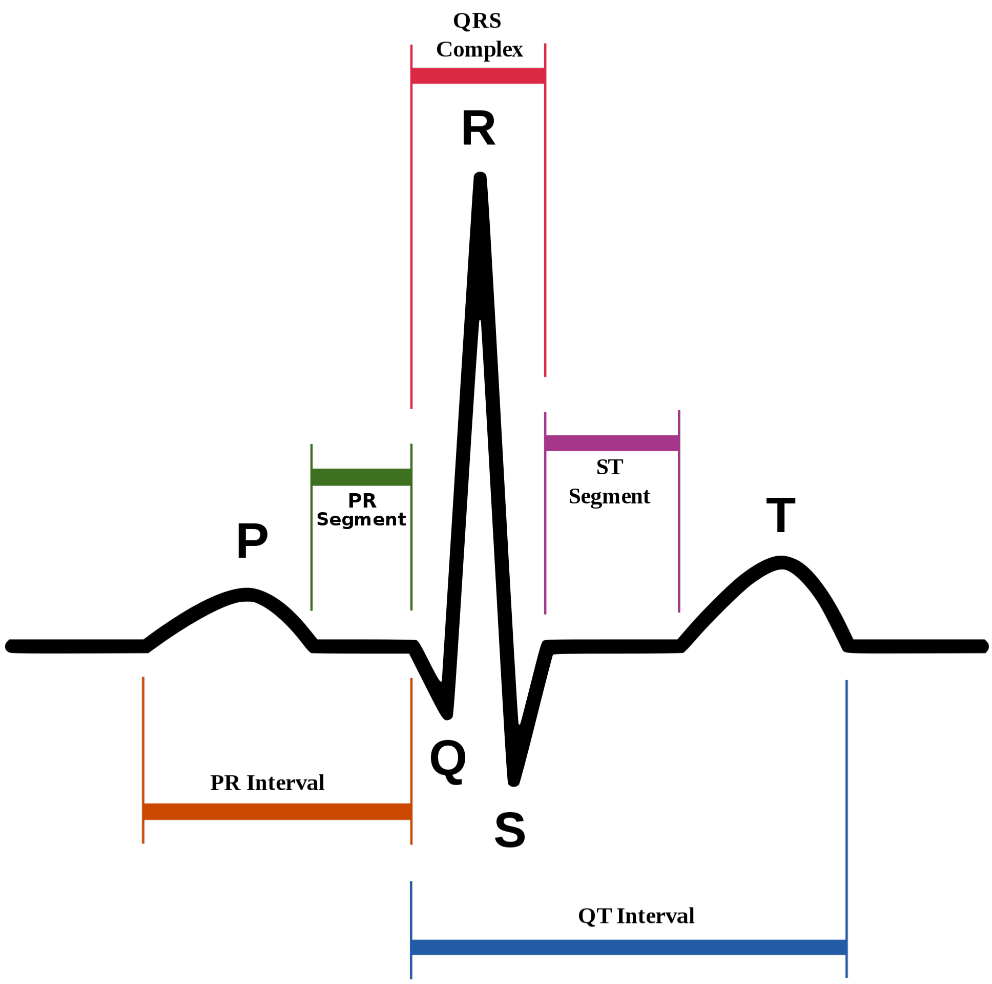

Figure 3.5: Graphical representation of a QRS wave [51].

The performance of ECG analyzing system depends mainly on the accurate and reliable detection of the QRS complex, as well as T- and P waves. The P-wave represents the activation of the upper chambers of the heart, the atria, while the QRS complex and T-wave represent the excitation of the ventricles or the lower chamber of the heart. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rate, the ST segment etc. can be performed.

In the normal sinus rhythm (normal state of the heart) the P-R interval is in the range of 0.12 to 0.2 seconds. The QRS interval is from 0.04 to 0.12 seconds. The Q-T interval is less than 0.42 seconds and the normal rate of the heart is from 60 to 100 beats per minute. So, from the recorded shape of the ECG, it is possible to know whether the heart activity is normal or abnormal. The electrocardiogram is a graphic recording or display of the time variant voltages produced by the myocardium during the cardiac cycle. The P-, QRS- and T-waves reflect the rhythmic electrical depolarization and repolarization of the myocardium associated with the contractions of the atria and ventricles. The normal values for the amplitude and duration of the different parts of the ECG wave features are expressed in Fig. 3.6. and 3.7.

AMPLITUDE	
P-Wave	0.25 mV
R-Wave	1.60 mV
Q-Wave	25% R Wave
T-Wave	0.1 to 0.5 mV

Figure 3.6: Amplitudes of a ECG wave features [51].

The Heart Rate, the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm) is the easiest feature that can be extracted. However, for this work and for psychological feedback the

DURATION	
P-R interval	0.12 to 0.20 s
Q-T interval	0.35 to 0.44 s
S-T interval	0.05 to 0.15 s
P-Wave interval	0.11 s
QRS interval	0.09 s

Figure 3.7: Duration of a ECG wave features [51].

most important feature is the one called Heart Rate Variability.

Heart Rate Variability is a measure which indicates the variation in heartbeats within a specific timeframe. The unit of measurement is milliseconds (ms). There are different ways to calculate HRV, but they all have to do with the amount of variation in the intervals between heartbeats. HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system (ANS) processes. HRV is an emergent property of interdependent regulatory systems which operate on different time scales to help us adapt to environmental and psychological challenges. HRV reflects regulation of autonomic balance, blood pressure (BP), gas exchange, gut, heart, and vascular tone, which refers to the diameter of the blood vessels that regulate BP, and possibly facial muscles [51].

Time-domain indices of HRV quantify the amount of variability in measurements of the interbeat interval (IBI), which is the time period between successive heartbeats (see Fig. 3.8.). These values may be expressed in original units or as the natural logarithm (Ln) of original units to achieve a more normal distribution [57].

Heart rate variability time-domain indices quantify the amount of HRV observed during monitoring periods that may range from 1min to 24h. These metrics include the SDNN, SDRR, SDANN, SDNN Index, RMSSD, NN50, pNN50, HR MaxHR Min, the HRV triangular index (HTI), and the Trian-

HRV time-domain measures.

Parameter	Unit	Description
SDNN	ms	Standard deviation of NN intervals
SDRR	ms	Standard deviation of RR intervals
SDANN	ms	Standard deviation of the average NN intervals for each 5 min segment of a 24 h HRV recording
SDNN index (SDNNI)	ms	Mean of the standard deviations of all the NN intervals for each 5 min segment of a 24 h HRV recording
pNN50	%	Percentage of successive RR intervals that differ by more than 50 ms
HR Max − HR Min	bpm	Average difference between the highest and lowest heart rates during each respiratory cycle
RMSSD	ms	Root mean square of successive RR interval differences
HRV triangular index		Integral of the density of the RR interval histogram divided by its height
TINN	ms	Baseline width of the RR interval histogram

Figure 3.8: HRV Time Domain measures [52]

gular Interpolation of the NN Interval Histogram. Where appropriate, the authors reported accepted minimum short-term and proposed ultra-short-term measurement periods [52].

SDNN The standard deviation of the IBI of normal sinus beats (SDNN) is measured in ms. "Normal" means that abnormal beats, like ectopic beats (heartbeats that originate outside the right atrium's sinoatrial node), have been removed. While the conventional short-term recording standard is 5min, researchers have proposed ultra-short-term recording periods from 60s to 240s. The related standard deviation of successive RR interval differences (SDSD) only represents short-term variability. In short-term resting recordings, the primary source of the variation is parasympathetically-mediated RSA, especially with slow, paced breathing (PB) protocols. The SDNN is more accurate when calculated over 24h than during the shorter periods monitored during biofeedback sessions. Longer recording periods provide data about cardiac reactions to a greater range of environmental stimulation. In addition to cardiorespiratory regulation, extended measurement periods can index the heart's response to changing workloads, anticipatory central nervous activity involving classical conditioning, and circadian processes, including sleep-wake cycles. Twenty-four-hour recordings reveal the SNS contribution to HRV. The SDNN is the "gold standard" for medical stratification of cardiac risk when recorded over a 24h period. SDNN values predict both morbidity and mortality.

SDRR The standard deviation of the IBIs for all sinus beats (SDRR), including abnormal or false beats, is measured in ms. As with the SDNN, the SDRR measures how these intervals vary over time and is more accurate when calculated over 24h because this longer period better represents slower processes and the cardiovascular system's response to more diverse environmental stimuli and workloads.

SDANN The standard deviation of the average normal-to-normal (NN) intervals for each of the 5min segments during a 24h recording (SDANN) is measured and reported in ms like the SDNN. This refers to IBIs calculated after artifacting the data. SDANN is not a surrogate for SDNN since it is calculated using 5min segments instead of an entire 24h time series and it does not provide additional useful information.

SDNN Index (SDNNI) The SDNNI is the mean of the standard deviations of all the NN intervals for each 5min segment of a 24-h HRV recording. Therefore, this measurement only estimates variability due to the factors affecting HRV within a 5-min period. It is calculated by first dividing the 24h record into 288 5min segments and then calculating the standard deviation of all NN intervals contained within each segment. The SDNNI is the average of these 288 values. The SDNNI primarily reflects autonomic influence on HRV. The SDNNI correlates with VLF power over a 24-h period.

NN50 The number of adjacent NN intervals that differ from each other by more than 50ms (NN50) requires a 2min epoch.

pNN50 The percentage of adjacent NN intervals that differ from each other by more than 50ms (pNN50) also requires a 2-min epoch. Researchers have proposed ultra-short-term periods of 60s. The pNN50 is closely correlated with PNS activity. It is correlated with the RMSSD and HF power. However, the RMSSD typically provides a better assessment of RSA (especially in older subjects) and most researchers prefer it to the pNN50. This may be a more reliable index than short-term SDNN measurements for the brief samples used in biofeedback.

RMSSD The root mean square of successive differences between normal heartbeats (RMSSD) is obtained by first calculating each successive time difference between heartbeats in ms. Then, each of the values is squared and the result is averaged before the square root of the total is obtained. While the conventional minimum recording is 5min, researchers have proposed ultra-short-term periods of 10s, 30s, and 60s. The RMSSD reflects the beat-to-beat variance in HR and is the primary time-domain measure used to estimate the vagally mediated changes reflected in HRV. Twenty-four-hour RMSSD measurements are strongly correlated with pNN50 and HF power. This will be the method used, because it allows to use ultra short periods of time.

3.3 Bitalino

Biosignals have been used in the healthcare and medical domains for more than 100 years. The application of engineering principles and devices in the field has proven to be of paramount importance, leading to remarkable technical, methodological, and scientific achievements. Today, biosignals are an increasingly popular research topic within the global engineering community: their potential applications far extend the medical arena, paving the way for the nascent field of physiological computing [21].

Physiological computing can be generally defined as the study and development of interactive software and hardware systems capable of sensing, processing, reacting, and interfacing the digital and analog worlds. Physical computing researchers have the Arduino and its successors and predecessors, but the physiological computing community lacks a comparable tool. Biosignals have specific requirements for which typical physical computing platforms are not particularly tuned, and many projects end up heavily bounded by the high cost and limited access to suitable hardware materials. Building on the guiding principles of existing physical computing hardware platforms.

BITalino is a highly versatile toolkit designed to make biosignals available for anyone interested in innovative and creative engineering in a physiological computing framework. The bitalino's hardware (Fig.3.9) consists of a low-cost, modular wireless biosignal acquisition system, with a credit card-sized form factor that integrates multiple measurement sensors for bioelectrical and biomechanical data acquisition. The digital back end is supported by a control block based on the ATmega328P microcontroller, a power management block, and a communication block that uses a Class II Bluetooth v2.0 module for wireless data transfer; two auxiliary connectivity blocks enable RJ22 plugs to be added to the device.

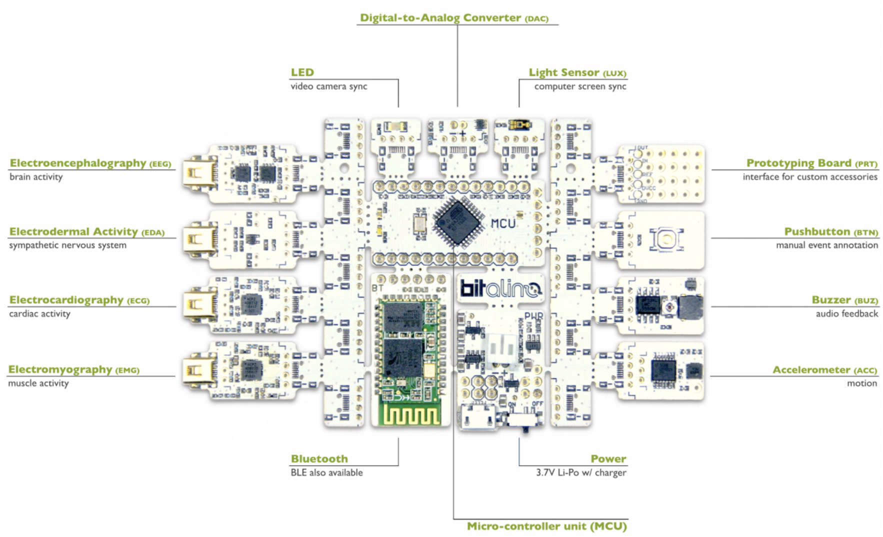

Figure 3.9: BITalino (r)evolution Board with Bluetooth connectivity [14].

Technical specifications	
Sampling Rate	Configurable to 1, 10, 100 or 1000 Hz
Analog Ports	4 input (10-bit) + 2 input (6-bit)
Digital Ports	4 input (1-bit) + 4 output (1-bit)
Data Link	Class II Bluetooth v2.0 (range up to 10m)
Sensors	EMG; ECG; EDA; Accelerometer; Light
Actuators	LED
Weight	30g
Size	100x60 mm

Figure 3.10: BITalino technical specifications [14].

The electrodes used for acquiring the EDA and ECG were the same (Fig. 3.11). They are Gelled Self-adhesive Disposable Ag/AgCl electrodes, according to recommendations for EDA from the Society for psychophysiological research in 2012 [6] and the recommendations for ECG with Bitalino by Smisek et al. in 2016, these electrodes allow a good acquisition of the signals [53].

Figure 3.11: Electrodes used for EDA and ECG

3.3.1 EDA sensor

The EDA sensor is capable of measuring the skin activity with high sensitivity measurement power in a miniaturized form factor. Some of the applications of this sensor include detection of changes in the attentive, cognitive and emotional states. Sweat glands secretion is a process that allows our body to regulate its temperature, but it is also associated the sympathetic nervous system activity. Whenever we become aroused (e.g. nervous) or relaxed, that state is partially translated into the sweat production or inhibition at the glands on our hands palms and feet. This changes the resistance of our skin; Electrodermal Activity (EDA) monitoring enables the translation of these resistance changes into numerical values, allowing its use in a wide array of applications. Known uses of this sensor include emotional mapping, the polygraph test (aka lie detector), and also stress / relaxation biofeedback. The physical aspect and dimensions of bitalino's EDA sensor and specifications are shown in Fig.3.12. and Fig.3.13. respectively.

The EDA sensor has a transfer function Fig.3.14. , which can be used for transform the values obtained by the sensor to the real values in the appropriate magnitudes, $\mu S(microsiemens)$.

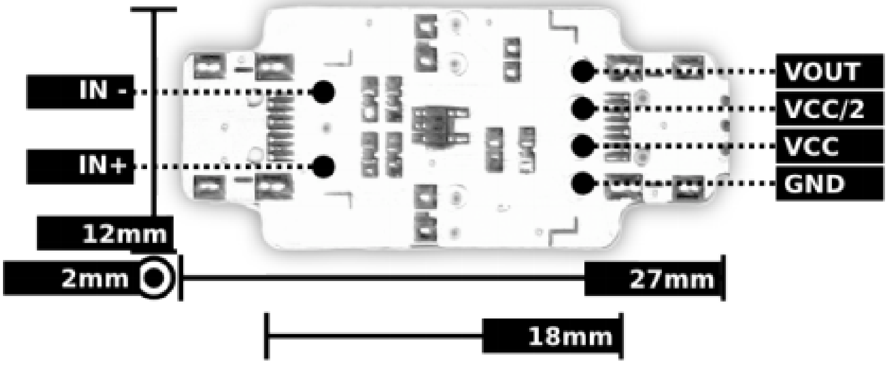

Figure 3.12: Pin-out and physical dimensions of EDA sensor [16].

Range	0-25 μS (with VCC=3.3V)
Bandwith	0-2.8 Hz
Consumption	0.72 mA
Input Voltage Range	1.8-5.5 V

Figure 3.13: EDA sensor technical specifications [16].

$[0\mu S, 25\mu S]$

$$EDA(\mu S) = \frac{\frac{ADC}{2^n}.VCC}{0.132}$$

$$EDA(S) = EDA(\mu S).1\times10^{-6}$$

$VCC = 3.3V$ (operating voltage)
$EDA(\mu S)$ – EDA value in micro-Siemens (μS)
$EDA(S)$ – EDA value in micro-Siemens (S)
ADC – Value sampled from the channel
n – Number of bits of the channel[1]

Figure 3.14: EDA sensor transfer function [16]

The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC); in BITalino the first four channels are sampled using 10-bit resolution (n = 10), while the last two may be sampled using 6-bit (n = 6).

For acquiring the signals it is necessary to use electrodes attached to the skin of the subject. According to the publication from the Society for psychophysiological research in 2012 [6] there are five different positions where electrodes can be placed in order to obtain a good quality signal. The best placement for electrodes is on the feet. However, as this research is for athletes it is concluded that the best placement for electrodes is palm of the non dominant hand (Fig. 3.15).

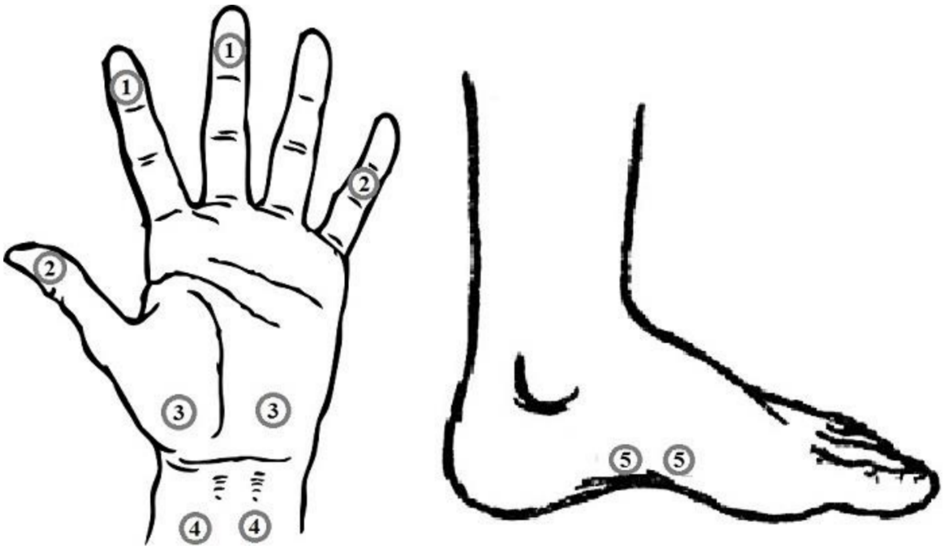

Figure 3.15: Placement of electrode pairs on different measuring sites: 1.) Distal phalanxes of index and middle finger, 2.) Distal phalanx of thumb and medial phalanx of little finger. 3.) Thenar and hipothenar eminence at the palm of hand, 4.) Wrist, 5.) Medial site on the inner side of the foot [45].

3.3.2 ECG sensor

Heartbeats are triggered by bioelectrical signals of very low amplitude generated by a special set of cells in the heart (the SA node). Electrocardiography (ECG) enables the translation of these electrical signals into numerical values, enabling them to be used in a wide array of applications. The sensor allow data acquisition not only at the chest ("on-the-person"), but also at the hand palms ("off-the-person"), and works both with pre-gelled and most types of dry electrodes. The bipolar configuration is ideal for low noise data acquisition. The physical aspect and imensions of bitalino's ECG sensor and specifications are shown in Fig.3.16. and Fig.3.17.

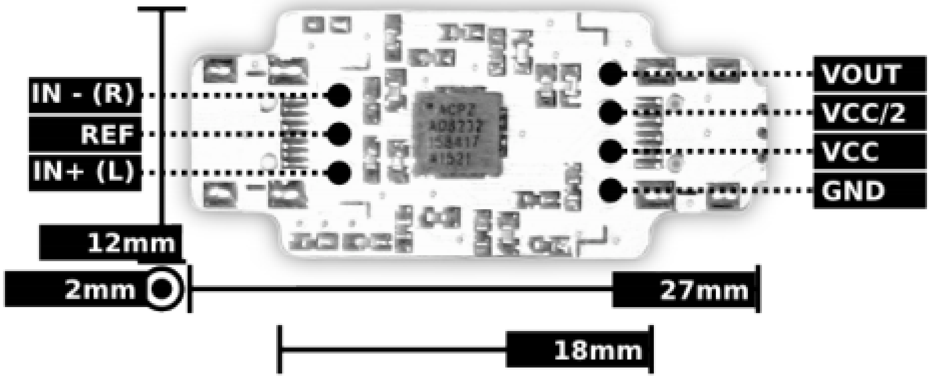

Figure 3.16: Pin-out and physical dimensions of ECG sensor [15]

Gain	1100
Range	± 1.5 mV (with VCC=3.3V)
Bandwith	0.5-40 Hz
Consumption	0.17 mA
Input Voltage Range	2.0-3.5 V
Input Impedance	7.5 GOhm
CMRR	86 dB

Figure 3.17: ECG sensor technical specifications [15]

The ECG sensor has a transfer function Fig.3.18, which can be used for transform the values obtained by the sensor to the real values in the appropriate magnitudes, Volts.

The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC); in BITalino the first four channels are sampled using 10-bit resolution (n = 10), while the last two may be sampled

[-1.5mV, 1.5mV]

$$ECG(V) = \frac{\left(\frac{ADC}{2^n} - \frac{1}{2}\right).VCC}{G_{ECG}}$$

$$ECG(mV) = ECG(V).1000$$

VCC = 3.3V (operating voltage)
G_{ECG} = 1100 (sensor gain)

$ECG(V)$ – ECG value in Volt (V)
$ECG(mV)$ – ECG value in millivolt (mV)
ADC – Value sampled from the channel
n – Number of bits of the channel[1]

Figure 3.18: ECG sensor transfer function [15]

using 6-bit (n = 6).

The electrodes placement for the ECG was selected following the recommendations of Smisek et al. (2016) [53] where they conclude that the best placement for electrodes is Fig. 3.19.:

- Plus, under right clavicula
- Minus, under left musculus pectoralis major
- Reference, under left clavicula

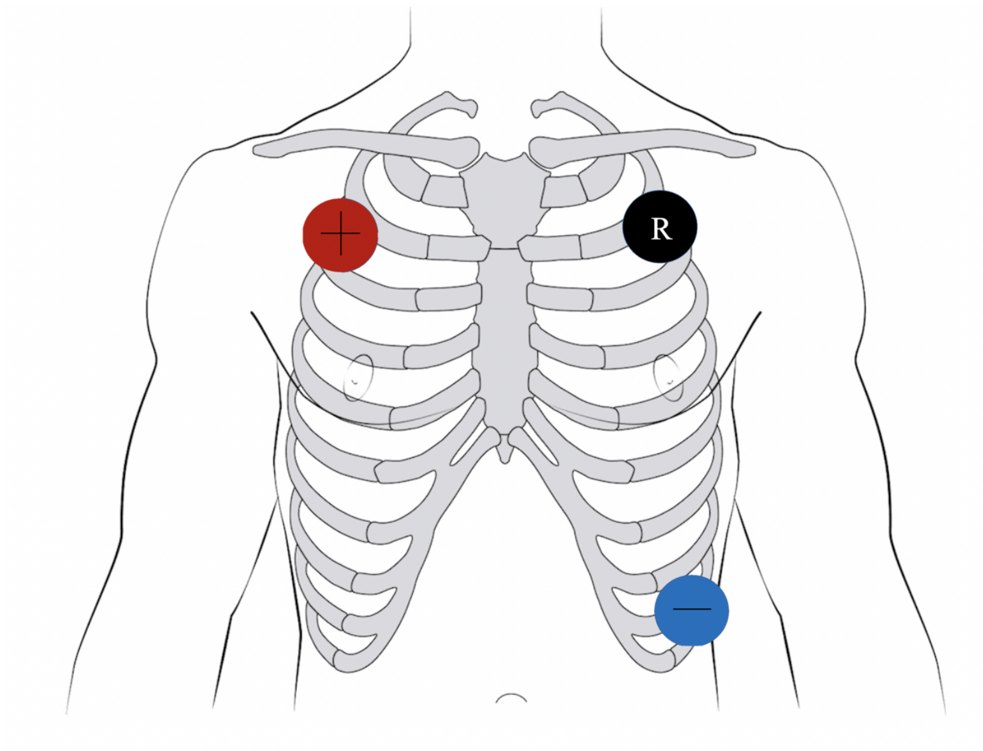

Figure 3.19: ECG electrode placement according to [53].

Chapter 4

System Development

This chapter focuses on the design and development of the system realised in this work. The first part of this work is dedicated to the analysis of existing wearable devices, in order to understand which are their main functionalities and components and the psychology in sport works. In the following sections, a complete description of the system is carried out. The steps needed to do to get the final aim of the device focusing in both, on the hardware components and on the implementation of the software part.

The final aim of the device and the application is to send a tactile stimulus when the player is in the optimal zone of performance according to his/her psychological state. In order to achieve the optimal zone of performance two test are done before for each user, one to acquire the skin conductance level (SCL) and the second one to find each optimal performance zone, which is done in the field.

4.1 Skin Conductance Level Test

The baseline is the HRV and the arousal of the person in normal conditions when the person is relaxed. This test is performed in order to find the values of EDA and HRV of each player for relaxed state and for stressed state. The International Affective Picture System (IAPS) method will be used for this test.

This method is a database of pictures designed to provide a standardized set of pictures for studying emotion and attention that has been widely used in psychological research [38, 37]. The IAPS was developed by the National Institute of Mental Health Center for Emotion and Attention at the University of Florida. In 2005, the IAPS comprised 956 color photographs ranging from everyday objects and scenes, such as household furniture and landscapes, to extremely rare or exciting scenes, such as mutilated bodies and erotic nudes.

IAPS pictures have been used in studies using a variety of psychophysiological measurements such as skin conductance [17] and heart rate [7]. The images have got prior ratings based on valence and arousal ratings. Quadratic contrasts on arousal ratings (ranging from 0, very calm, to 9, very arousing) to compare emotional categories (unpleasant and pleasant) with the neutral category. The subject's arousal changes depending on the different kind of images showed, the change in arousal is illustrated in Fig. 4.1.

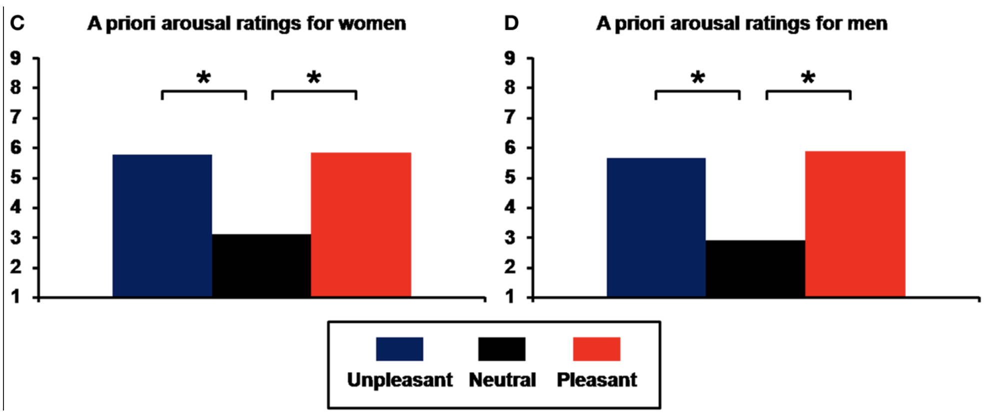

Figure 4.1: Means of a priori ratings for unpleasant, neutral, and pleasant pictures selected from the International Affective Picture System (IAPS) [17].

A computer's screen is used to project the visual stimuli (Presentation of random images,). One sets of one hundred pictures were selected from

IAPS: unpleasant (U) and one grey photo used as a neutral (N) one. Between two images a scrambled photo was projected. The decision of project a scrambled photo (S) instead of a white landscape is because the projection of a scrambled photo makes the subject to forget the previous image and concentrate for the next one. So the sequence is, N or U followed for S, N or U, S, N or U, S... An example of the different photos is showed in Fig. 4.2

Figure 4.2: Scrambled image, example of Unpleasant image and Neutral image

The test starts and the subjects are monitored for one minute. This is to the fact that when a person is getting recorded it use to be more nervous than the normal state. The first minute is to stabilise the baseline. After it, the projection of the images starts. In this case 45 neutral or unpleasant images are projected and a scrambled image between them, in total 90 images. The images will be projected for 6 seconds, while the scrambled one 2 seconds, a total of 6 minutes trial.

During the experiment two kind of markers are used, one for the neutral image and one for the unpleasant, EDA will be studied separately for both events.

After this, the data can be processed and analysed to get the psychological state of the subject when it is looking at unpleasant photo or neutral one. With this experiment the SLC is extracted when they are looking at neutral photos and SCR when they are looking at unpleasant ones.

4.2 Test 2: IZOF searching

The second test that must be done to achieve the results is the one dedicated to search the Individual Zone of Optimal Performance of arousal and HRV. In order to obtain this zone, which is a range, it is needed to perform a field test to evaluate the performance of each athlete. The IZOF is personal, each person has its one and could be equal to the ones of other people or not.

This test has to be done in the field, where the player does its activity. It consists in analyse the player when doing the activity which is wanted to improve. In the case of this project the anlaysed activity is a drop in rugby, which means kick the ball from different part of the field and look if the result is good or not. This can be done for the activities which are "dead ball" movements (like penalty in football, serve in tennis...).

This tests consists in let the player do the activity from randomized parts of the field/court a high number of times and register its EDA and HRV and the result of the performance (good or bad). After it, by means of machine learning it is possible to classify the registers and get the range of values for which the player is obtaining the best results, in other words his/her individual zone of optimal performance.

4.3 System components: the hardware part

The device is composed by:

1. Bitalino and its sensors
2. Arduino
3. Computer

Bitalino is used in order to acquire the physiological signals and Arduino to send the tactile feedback to the user.

As was mentioned in Chapter 3, where Bitalino definition is found, both sensors are used, one for EDA and the other one for ECG analysis. The signals acquired with them are processed by a computer using MATLAB2019b.

Having analysed the biosingals got form Bitalino, to send the stimuli a small DC motor is used placed in the dominant hand wrist. The Dc motor is controlled using Arduino, which is connected wireless to the computer, via Bluetooth.
The choice is therefore to use a Bluetooth module, a standard technology for exchanging data over relatively short distances. Furthermore, all modern PCs have built-in Bluetooth connection capability, which avoids the need for additional connectors or instruments. The chosen product is the HC-06 Bluetooth module Fig. 4.3, a very common and popular device that can be found at very low prices. It features Bluetooth 2.0 connectivity and communicates trough Serial interface up to 10-15 meters away. Its dimensions are small, good for wearable devices (4.3 x 1.6 x 0.7 cm). This module features only four pins (RX and TX for serial transmission, ground and power), and it is therefore easy to connect and use.

The DC motor chose is a small one of 8 mm of width and 0.6kg of weight. Thanks to its shape and weight can be used without disturbing the player. The motor is sewn to a wristband, in order to let the user can feel perfectly the vibration.

4.3.1 Wirings

The wirings between the components are performed using standard jumper cables, which are simple electrical wires used to connect the

Figure 4.3: HC-06 Bluetooth Module

different pins. The presence of the pins allows easy connection to the cables, which have a compatible head at the end, so that it is possible to insert and eventually remove them just by a pushing or pulling action. The HC-06 has only four pins, that have to be connected as follows: the ground pin goes to the ground of the Arduino, the VCC is attached to the correspondent VCC on the Arduino (the ones which provide the voltage), while the RX an TX must be connected to two pins that support power modulated signals. Since all the digital I/O pins on the Arduino allow this connection, pins number 2 and 3 are selected for simplicity.

For the DC motor in order to avoid that the pins of Arduino UNO stand more current that they can, a complex circuit has to be used. A direct current, or DC motor is the most common type of motor. DC motors normally have just two leads, one positive and one negative. To control the DC motor, without changing the way that the leads are connected, a circuit called an H-Bridge can be used. An H bridge is an electronic circuit that can drive the motor in both directions. H-bridges are used in many different applications, one of the most common being to control motors in robots. It is called an H-bridge because it uses four transistors

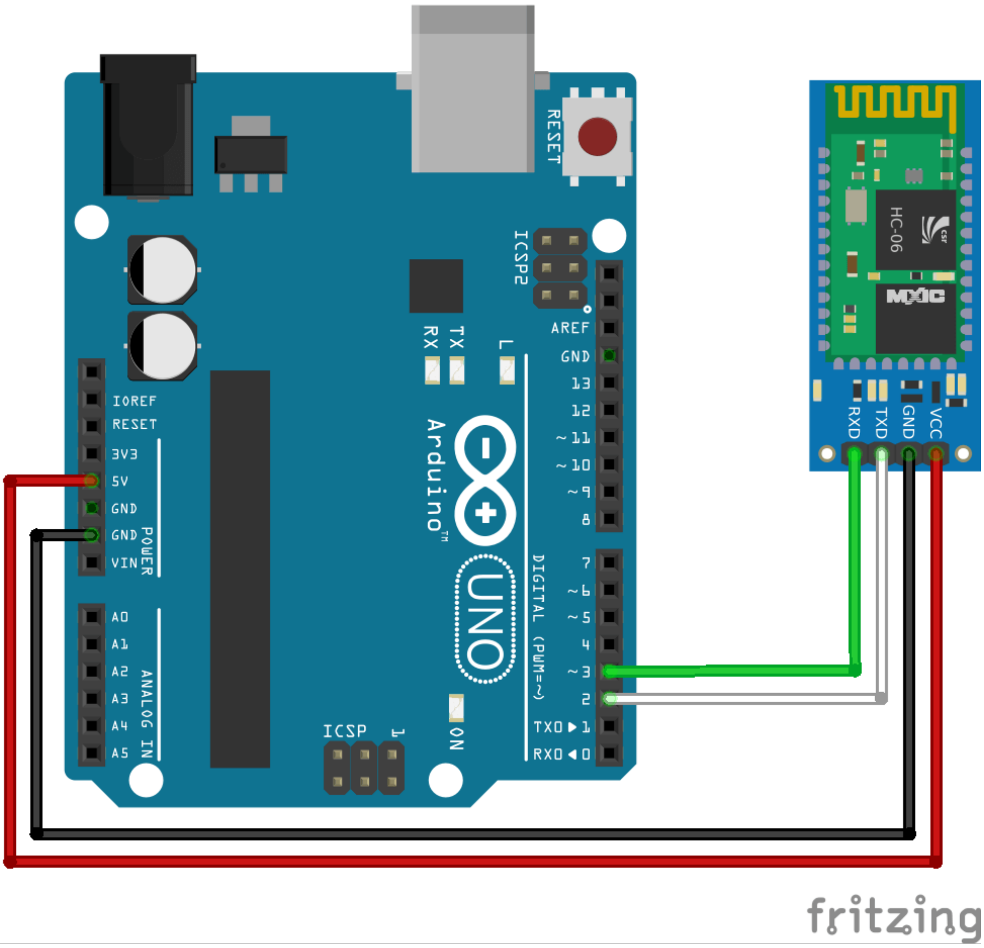

Figure 4.4: HC-06 Bluetooth Module Wiring

connected in such a way that the schematic diagram looks like an "H." Discrete transistors have to be used in order to make this circuit, also a diode and a 270 Ohms resistor. The wiring is shown in Fig. 4.5.

Arduino is connected to a portable battery of 9 V. The device final shape can be observed in Fig. 4.6 and Fig. 4.7.

4.4 How the system works: The software part

This section introduces and describes the software that have been developed to acquire, analyse and process the data. In the first part, the

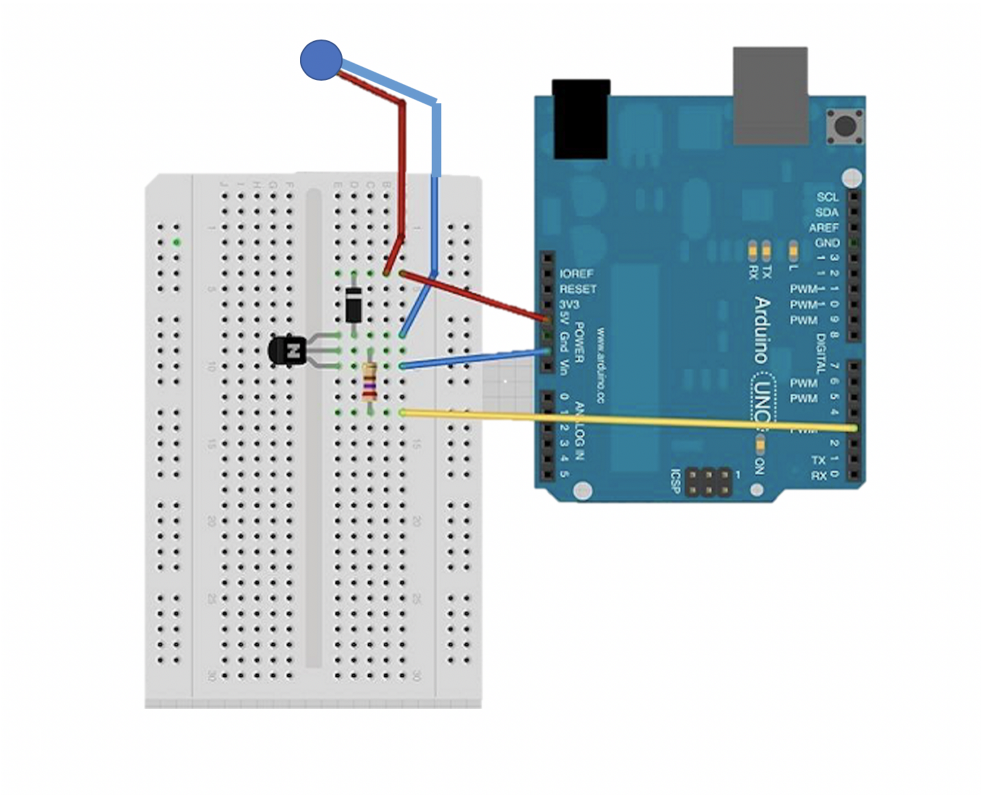

Figure 4.5: DC motor wiring with Arduino UNO

characteristics of the acquisition phase and the analysis of the signals are presented. The software used in this work are the Arduino IDE and MATLABR2019b. Arduino IDE is the open source programming environment associated with any Arduino board; it is therefore necessary in order to program the microprocessors. MATLAB has been chosen for its notable capability of dealing with complex numerical calculation and because it is well known and adopted in the engineering environment. In addition, the release version used in this work features new machine learning algorithms and functions recently added, which will be of great help in the recognition of the optimal performance zone.

During the three phases of the device (SCL acquisition, IZOF and performance) the data acquired by Bitalino has to follow different steps in order to get results and useful data. The steps followed are:

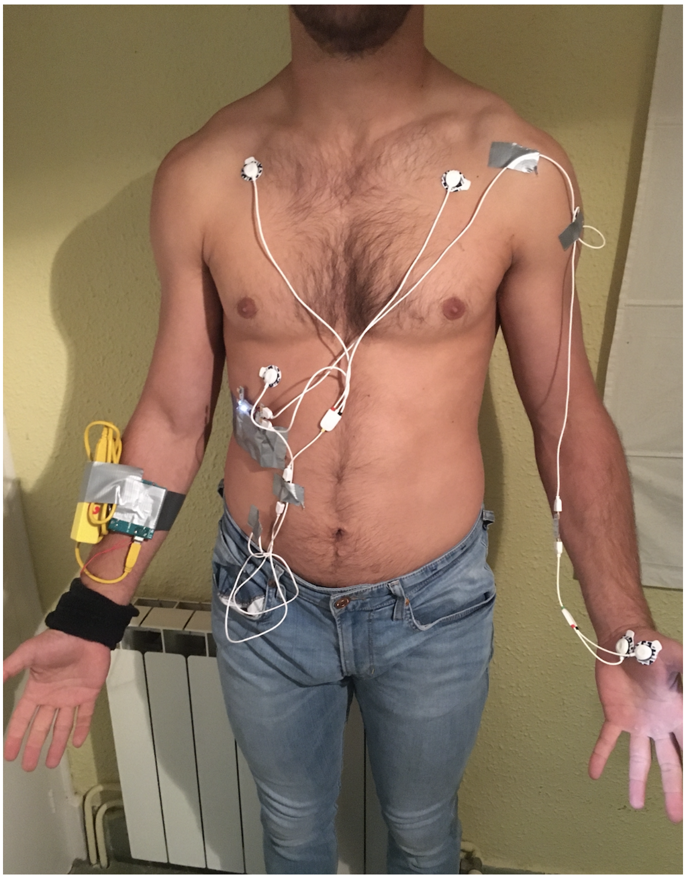

Figure 4.6: Final Device shape with Arduino Uno in dominant hand and Bitalino with EDA and ECG sensors

1. Acquire data in real time
2. Apply the sensor transfer function (TF)
3. Filtering
4. Analyse the data Learning (in IZOF searching phase)
5. Obtain results
6. Send the stimuli (Performance phase)

4.4.1 Data Acquisition

Bitalino can be connected with Matlab and using a simple function from the "BITalino Toolbox" for Matlab, it is able to read the values of all the Bitalino's channels.

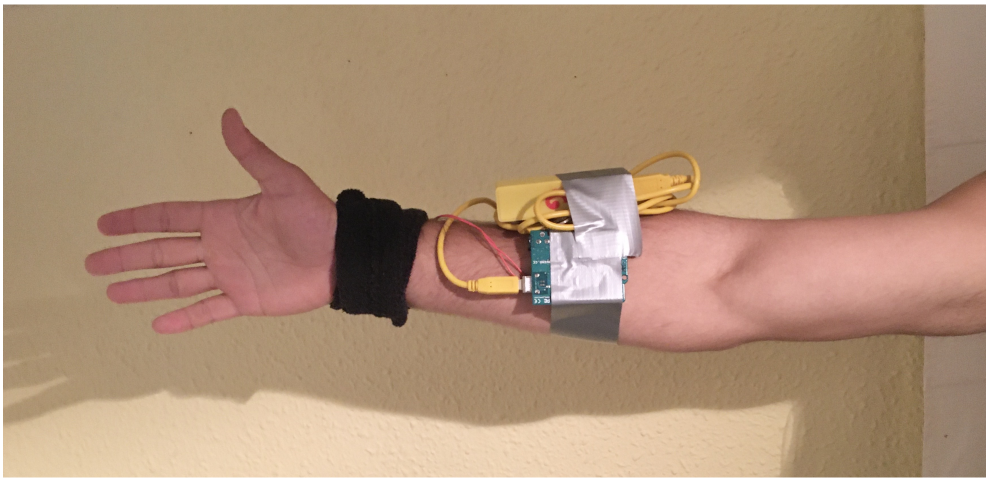

Figure 4.7: Detailed view of feedback part of the device, Arduino UNO, bluetooth, wristband with sewed DC motor and portable battery

With this simple command it is able to start reading the values and the values are ready to be processed.

```
% Start background acquisition
b.startBackground;
```

4.4.2 Sensor Transfer Function

Bitalino acquires the values, they have to be processed and converted to real values whit units. For doing this the TF of the sensors listed in Chapter 3 are necessary. With simple commands the values obtained are converted to values with consistent units. Each sensor has its TF.

4.4.3 Filtering

The use of this kind of sensors introduce noise in the signals. For this reason, the signals have to be filtered previously and the they can be analysed perfectly. The signals are quite noisy and therefore some parameters such as, for example, the number of peaks could be difficult to calculate accurately, and others could be distorted. It is believed that, given the kind of gestures targeted by the developed system, this data could be adopted effectively without too many complications. However,

in order to deal with smoother signals some filters are applied.
As there are two different kind of signals, different filters are applied in order to make each signal as clear as possible.

For EDA the best results are obtained applying a Low-Pass Filter at 0.5 Hz and a Gaussian filter $\sigma 6 - 10 seconds$[6].

A low-pass filter (LPF) is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency (Fig. 4.8).

The Gaussian one, is a filter whose impulse response is a Gaussian function (or an approximation to it, since a true Gaussian response is physically unrealizable). Gaussian filters have the properties of having no overshoot to a step function input while minimizing the rise and fall time (Fig. 4.9) [3].

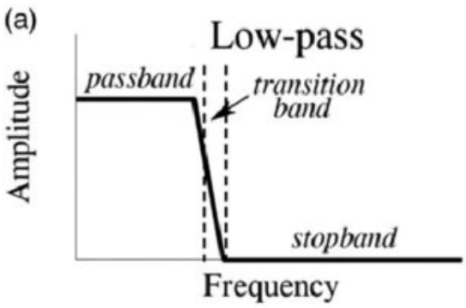

Figure 4.8: Low Pass Filter [42]

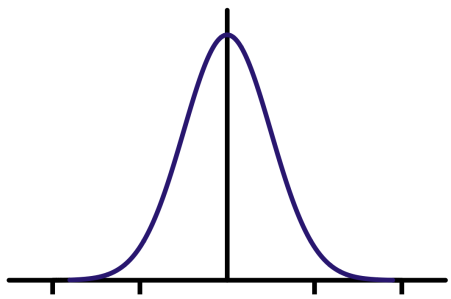

Figure 4.9: Gaussian filter [31]

The electrocardiogram (ECG) signals contain many types of noises-baseline wander, powerline interference, electrode motion artifact noise. Baseline wander is a low-frequency noise of around 0.5 to 0.6 Hz. To remove it, an elliptic filter with a Low of cut-off frequency 5 to High cut off Frequency of 30 Hz can be used. Powerline interference (50 or 60 Hz noise from mains supply) can be removed by using a notch filter of 50 or 60 Hz cut-off frequency. Electrode motion artifact can be suppressed by minimizing the movements made by the subject [34] . A Butterworth filter is also used for extracting noise for ECG [49].

These filters are applied with Matlab. The results for EDA are shown in Fig. 4.10, Fig. 4.11 and Fig. 4.12. For ECG in Fig. 4.13 and Fig. 4.14 where it is possible to observe perfectly the ECG wave shape.

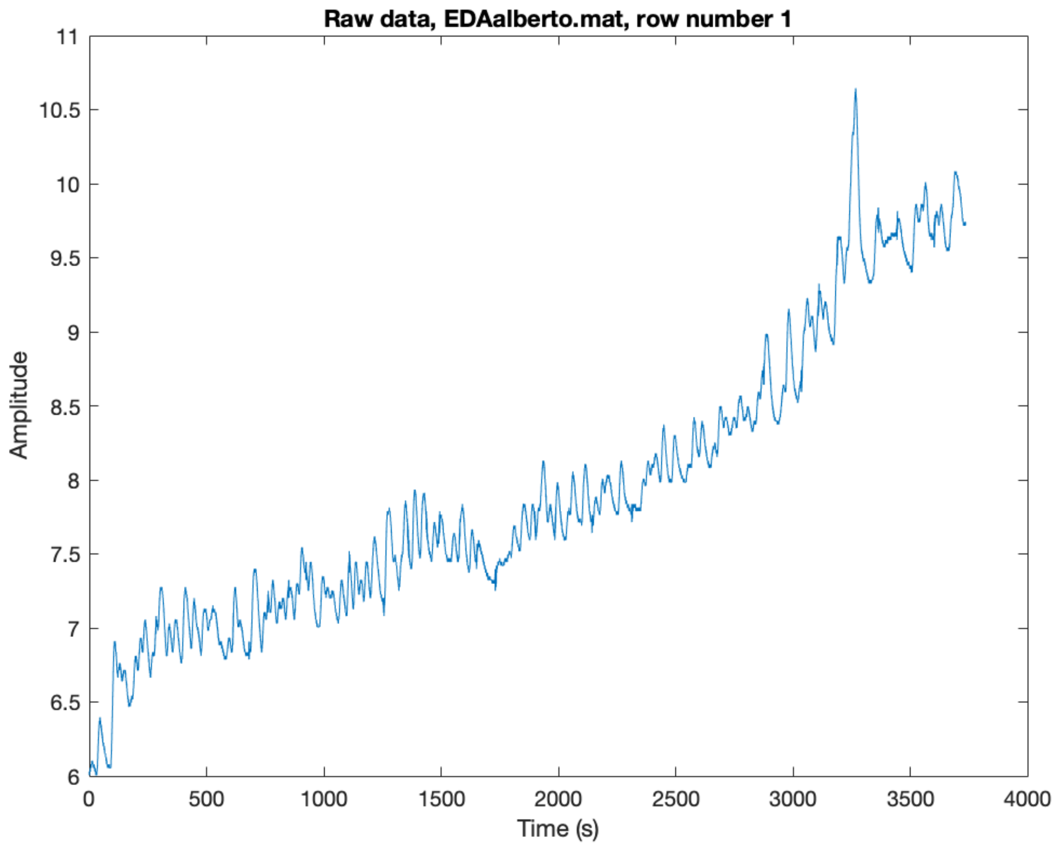

Figure 4.10: Raw data of the Subject 1 for EDA during baseline acquisition

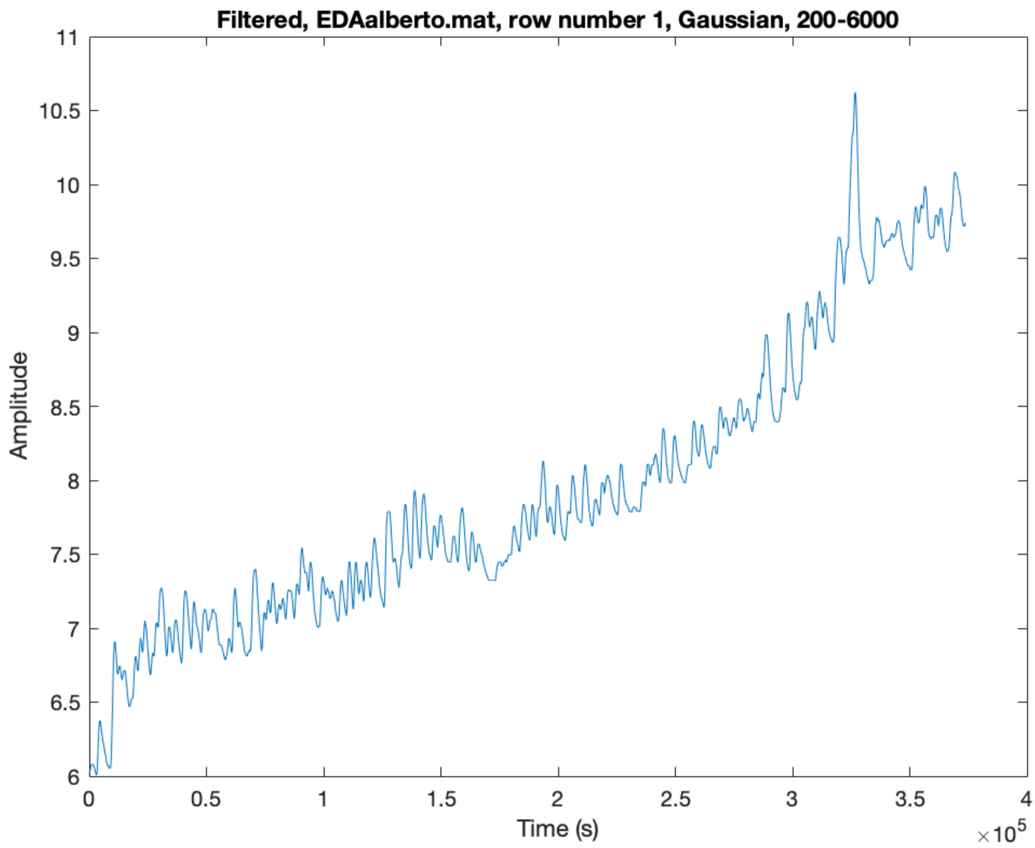

Figure 4.11: Gaussian Filtered data of the Subject 1 for EDA during baseline acquisition

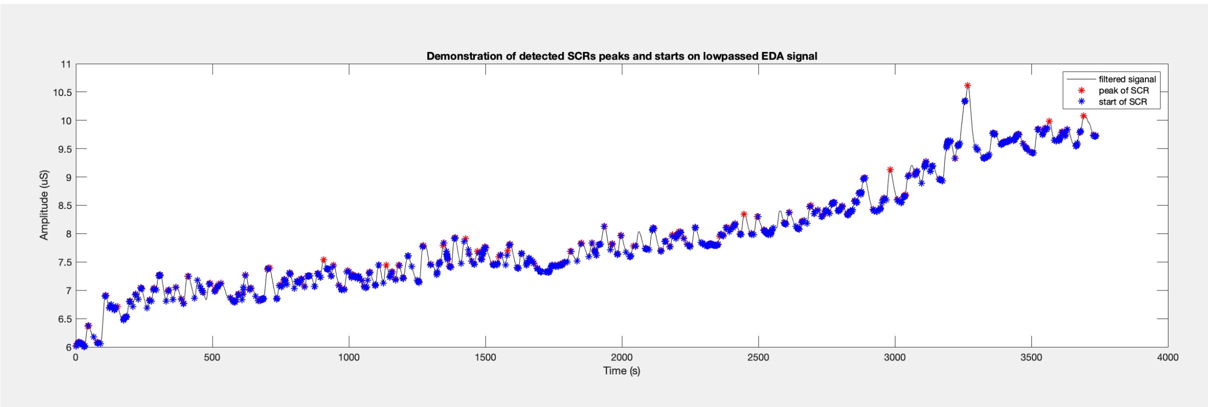

Figure 4.12: Low Pass Filtered data of the Subject 1 for EDA during baseline acquisition

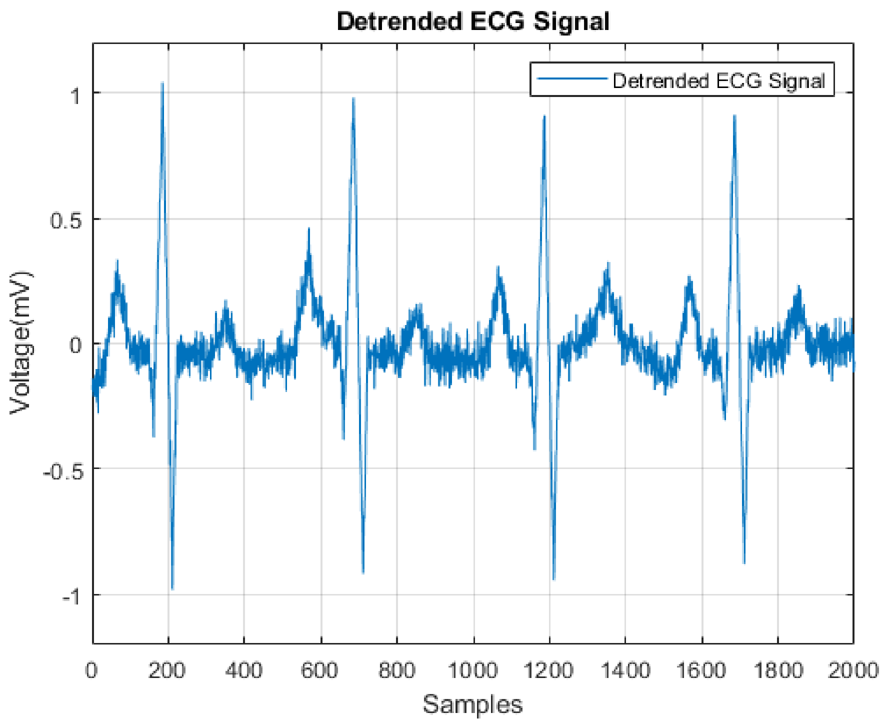

Figure 4.13: Raw data of the Subject 1 for ECG during baseline acquisition

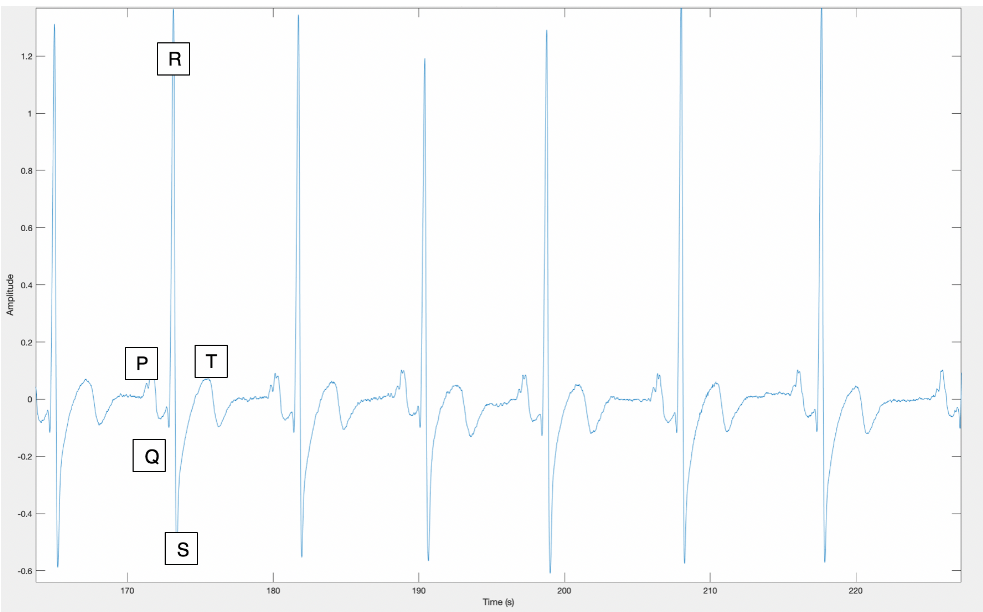

Figure 4.14: Filtered data of the Subject 1 for ECG during baseline acquisition

4.4.4 Machine Learning

Machine learning is a discipline that is aimed at studying and building algorithms that can learn from data. What this means is that those algorithms operate by developing a model based on inputs and using that to take decisions or make predictions, rather than following explicitly human-driven programmed instructions. The idea is that with machine learning it is possible to gain insight into a dataset, which can be very complex or unknown. Machine learning is a subfield of computer science and evolved from the study of pattern recognition, which instead has its origin in engineering. It is also closely related to computational statistics, which also focuses on prediction- making through the use of computers, but comes from the field of mathematics. In addition, any statistical modelling assumes a number of distributions while machine learning algorithms are generally agnostic of the distribution of all attributes.

Machine learning comprises a set of techniques and algorithms that help in dealing with vast datasets, where the high number of variables or the high number of observations make it unrealistic or sometimes even impossible to tackle the problem with traditional explicit algorithms. It has become very important recently because it is now possible to retrieve quickly a large quantity of data from a variety of sources and therefore there is the necessity to analyse and classify them in an automated and fast way. Thankfully, there are also available more powerful computers which help in tackling this problem, provided that researchers are able to implement the right techniques according to the situation.
The application field of machine learning is extremely wide, and its techniques are actively being used today, perhaps in many more cases than people expect. Example applications include email filtering, online search, data security, healthcare, marketing personalization, weather forecasts and of course pattern and activity recognition. In general, any field that needs to interpret and act on data can benefit from machine learning techniques.

Machine learning algorithms can be broadly divided into two main categories: supervised learning and unsupervised learning. Supervised learning involves building a model starting from a set of data and the correct output associated with that data, allowing the system to map a set of input variables to a response. In other words, the algorithm is given a series of elements, which are

usually vectors of features, and it is told at which group or class they belong to, so that it is able in future to classify new unknown data accordingly.
In unsupervised learning, instead, the training set contains data but no solutions; it involves looking for structures and patterns within a dataset without reference to a response or true result.

This thesis is going to use supervised learning.

Supervised learning techniques, as previously seen, are trained with datasets that contain the correct answers. They can be divided into two main classes, classification problems and regression problems. In classification problems, the response is discrete, meaning that we have a fixed number of possible classes to which the data can be assigned; the output represents the most likely class for a certain input. It is possible to have binary problems but, in general, there could be any number of response classes. For example, an activity tracker could be trying to determine the user's activity from his movements. In regression problems, there is instead a continuous output. The goal is to understand the relationship between the various factors, build a model with an explicit formula and use it to predict the outcome given certain feature values. An example is the calculation of fuel consumption of a car, given all its specifications. There are two typologies of regression models: parametric regression models and non-parametric regression models. In the first case, the model can be described using a closed formula, whose parameters are determined by fitting the model to the data. However, when the data has a large value of predictor variables, it could be difficult to build a correct parametric regression model, because including all the possible predictors can lead to an unnecessarily complicated model which does not generalise well to new data. Non-parametric models apply instead an algorithm to the data; in the aforementioned case of complex problems, they can provide a more accurate prediction but are difficult to interpret.

4.4.5 Support Vector Machines

A Support Vector Machine (SVM) algorithm is a binary classification method that classifies data by finding the best hyperplane that separates the classes. As can be seen in Fig. 4.15 , there can be an infinite number of planes dividing the data. The best boundary is the one that maximises the margin, which is the distance between the boundary and the closest observations. Since, in the end, the best solution depends only on the two closest elements, they take the name of support vectors. Once the model is set, new observations are simply classified by looking at which side of the boundary they lie. With real data, it is usually impossible to have a perfect separation between classes, meaning that there is no linear boundary that can correctly classify every observation. In this case, the goal remains to maximise the margin, but a penalty term for misclassified observations is introduced, thus modifying the position of the boundary according to their number and position. SVM usually performs well on datasets that have a large amount of variables, even if they contain very few cases on which to train the model.

It is relevant to notice that linear boundaries between classes are not suitable for all possible problems. However, Support Vector Machines can be extended to non-linear classification problems by performing a transformation of variables into a space where the classes are linearly separable. A final important remark is that even if SVMs work only for binary classification problems, they can be extended to multiclass problems by combining multiple binary classifiers.

4.4.6 Information obtantion

In order to obtain the results and information from the signals three steps are followed:

- Acquire signal
- Application of sensor TF (done with Matlab)
- Filtering

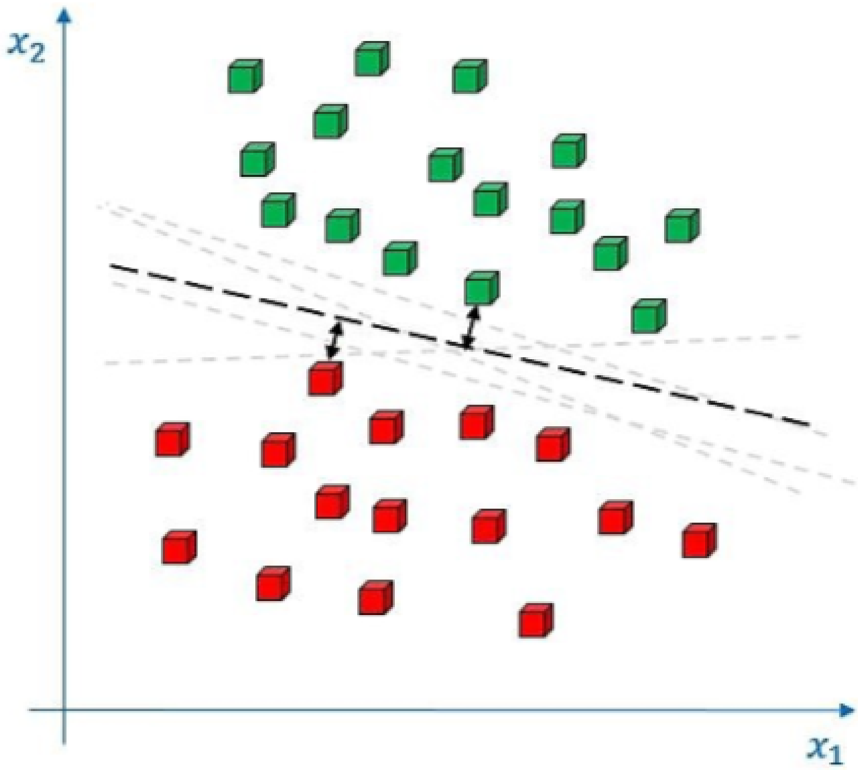

Figure 4.15: Support Vector Machine classification method

– Use of Ledalab and Matlab Toolbox to obtain important features from both signals

With Ledalab used in MATLAB it is possible to obtain the values of EDA for SCL and SCR using Continous Descomposition Analysis during baseline acquisition. The stressed one, are the EDA values obtained when the subject is looking at unpleasant photo and the relaxed one when the subject is looking at the grey landscape. With these results it is possible to know the stressed and relaxed values of each subject.

In the 2nd phase a technique of Machine Learning is used, the one called Support Vector Machine (SVM). In this phase the attempts of the player are observed and divided into two groups correct, when the ball goes inside the goal, incorrect when the ball goes outside. For each attempt the data of EDA and HRV are registered and also the result.

4.4.7 Tactile feedback

To send tactile stimuli from the data ARDUINO is used, so information got with MATLAB must be send to Arduino. To do this a MATLAB toolbox for Arduino is used. There are some functions to connect both software are found and they can be used to activate the vibration. When the HRV and EDA are on the range previously found where the player achieves the better performance, MATLAB will send the signal to Arduino in order to make the motor vibrate.
The toolbox is obtained from Matlab File Exchange website. The logic of the process flowchart is represented in Fig. 4.16.

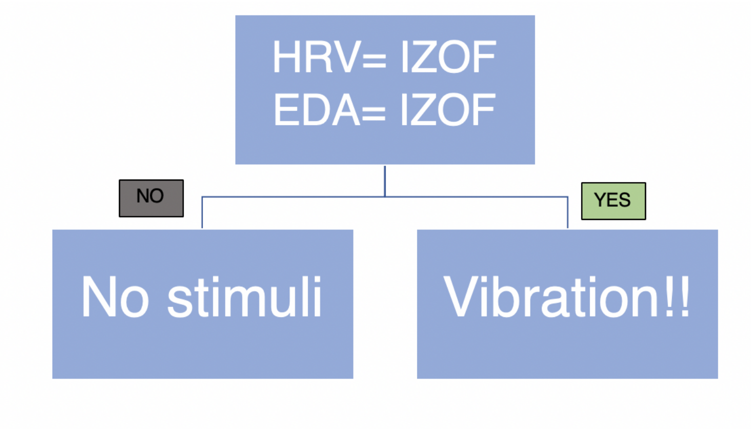

Figure 4.16: Flowchart of the recognition algorithm

4.4.8 Graphic Interface

The Matlab app inizialitation is shown in Fig. 4.17. Where you can register the data for a new player and proceed to baseline acquisition and find the optimal zone. In the other hand you can use the device with stored data of the player that has used before the device.

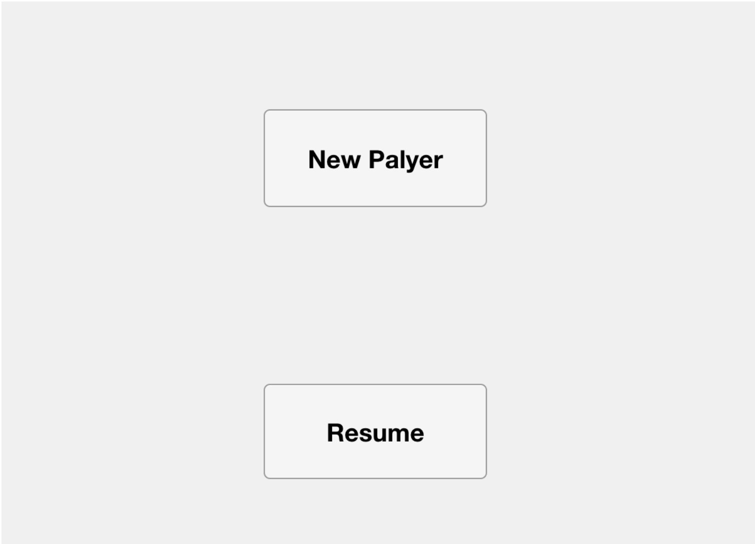

Figure 4.17: Initial Matlab application screen

When this screen has been passed if you selected the new player, a new screen asking for the name, sex and age will be found. Fig. 4.18.

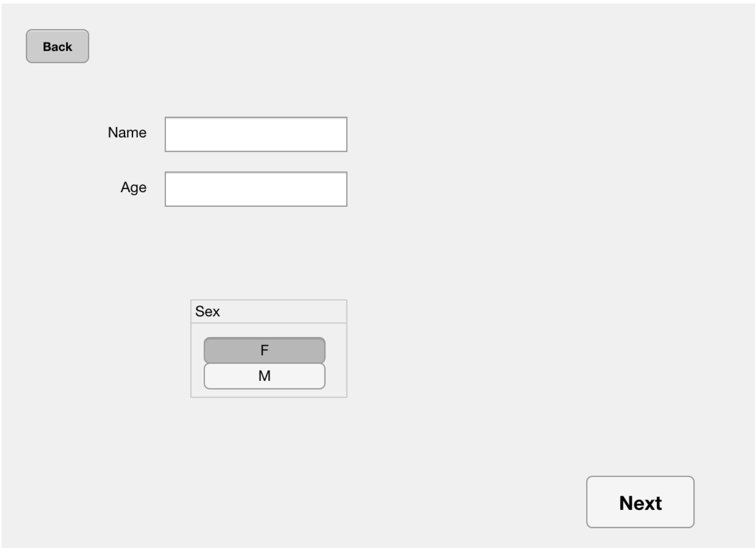

Figure 4.18: New player application screen

After introducing the player information or also when you select the option of using old data, the next screen let you select what you want to do Fig. 4.19. There are three options, one for acquisition of baseline, izof or for start using the device. In the case of new player you has to perform the three phases in the same order that are indicated, if not you cannot use the device.

Figure 4.19: Three options screen

In the second phase, in order to be able to find and interval of EDA and HRV which is the optimal performance zone, where the player has the psychological state which gives more points to him. In the Matlab app you need to select if the ball goes in or out, and the program makes the calculations depending on the result (Fig. 4.20).

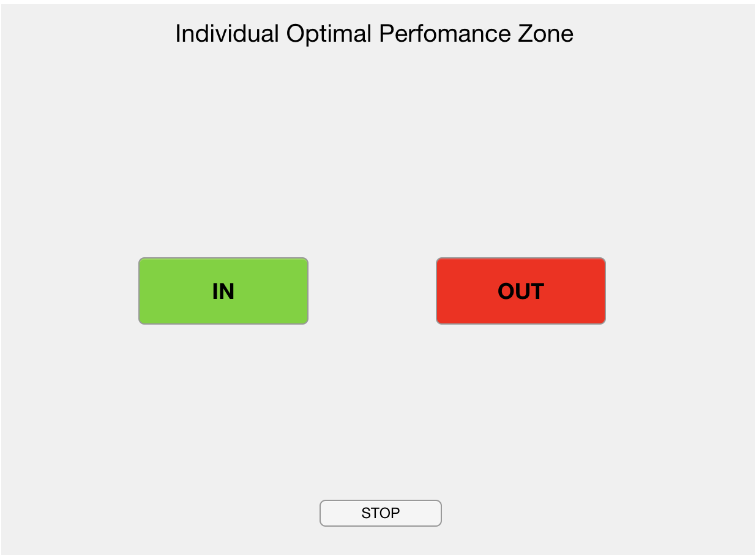

Figure 4.20: IZOF screen

In the 3rd phase the device is ready to be used. In this phase Matlab reads the value of the signals and send a vibration through Arduino to the player.

The app provides a real time signal visualisation and also a pause and stop button (Fig. 4.21).

Figure 4.21: App visualisation during performance

The process of evaluation and recognition of the psychological state is quite severe, as the data contained in the window is evaluated simultaneously by two models; EDA and HRV.

Chapter 5

System Testing

The aim of this section is to prove the effectiveness of the device and find the strengths and weakness of the device. For this aim, a sport to test it was selected and some professional player were asked to use the device in order to understand how it works and what could be improved. Rugby is a contact team sport. It is based on running with the ball in hand. In its most common form, a game is between two teams of 15 players using an oval-shaped ball on a rectangular field with H-shaped goalposts at each end. During a rugby match one of the players has to introduce the ball inside the H-shaped goalposts, if the player achieve the target the team wins points. It is a critical moment during the match, the player is tired and he/she has the tension and stress of the match. So the psychological state of the player and the capacity of being calm it is an important factor during this moment.
In this thesis the device will be tested in the situation of kicking the ball. The player has time to think before kicking, so we will try to achieve the best state performance for the player in this rest time.

The test will be done for the three phases:

1. SCL Acquisition
2. IZOF
3. Performance test

The first phase will be done with the participants seated looking at computer screen. The second one will be done on the field, where the players are going

Figure 5.1: Sequence photos of the movements of a rugby player kicking the ball during a match, credits: Sport Photo Gallery

to kick the ball from three different positions while Bitalino is acquiring data and the result of the kick and the psychological state, looking at EDA and HRV, in the moment of the action will be classified according the final result of the action (in or out the goal). These results, will be used to find the IZOF by machine learning and the total effectiveness of the player kicking the ball inside the goal will be used to compare it with the ones using the device.

5.1 Participants

The participants are professional rugby players integrating a team in the Spain first division. For this kind of tests it is important that athletes are not amateur. This is due to the fact that professional rugby players understand and have achieved perfectly the mechanisms for the performance and to achieve a good or bad results. They have the movements integrated and they know which consequence has each movement. A sequence photos of the action is showed in Fig. 5.1. The action of kicking the ball can be done in wherever inside the field, there are easy places and very difficult one.

The participants were six professional rugby players male with 26,3 (standard deviation 2,94) years of age, 21,7 (standard deviation 3,1) years playing rugby and 6,8 (standard deviation 2,6) years as professionals from the team Unió Esportiva Santboiana, last champion of the Spain King's Cup.

The tests were performed during the pre-season stage in Sant Boi (Catalunya), in UES's field during August- September 2019.

5.2 Devices used

The device used for doing the prototype of the device is Bitalino, so the test was carried out with it, Bitalino (r)evolution board. The data was recorded using the software provided by Bitalino, called OpenSignals. For live test Matlab program designed for capturing the signal values at real time was used.

SCRs and HRV were recorded using the constant-voltage method (0.5 V) at a sampling rate of 100 Hz, and all trials were low-pass filtered at 50 Hz. Ag-AgCl electrodes (8 mm diameter active area) were attached as shown in Chapter 3.

5.3 Design and procedure

For the first test the player has to be seated, calm and concentrated looking at a computer screen, where different images have been presented for 6 minutes. In this case the player will be seated and looking at the computer screen, not practicing sport.

The setup of the experiment is shown in Fig. 5.2 and 5.3, where the player is connected to Bitalino while looking at the screen. The second computer is the one getting the values in real-time and applying the markers each time a photo appears on the screen.

With this test the baseline have been acquired and with these results it is possible to pass to next step: find the IZOF.

For the second and three phase the test will be performed on the field. The test consists in evaluate qualitatively the performance of each player while he is monitored with Bitalino EDA and ECG sensor.

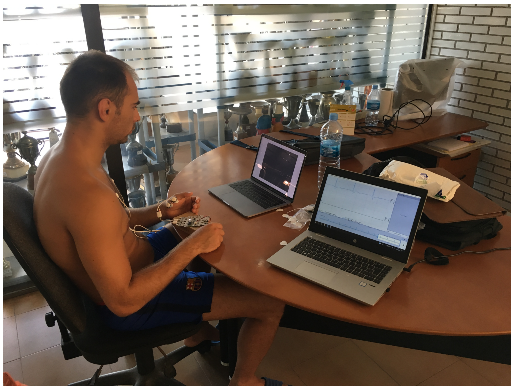

Figure 5.2: Set up of baseline acquisition

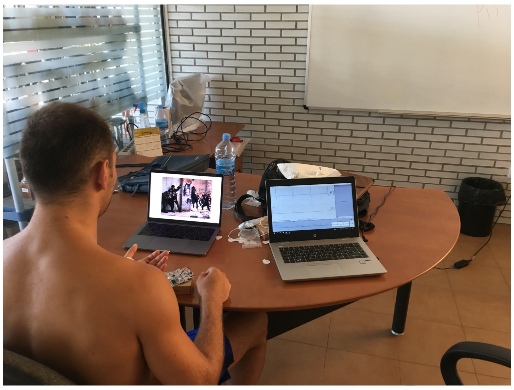

Figure 5.3: Set up of baseline acquisition

The performance is evaluated following the criteria inside or outside the goal. A good performance will be inside a bad one outside.

The test will be divided in 3 places. The places are selected in order to have an easy target, moderate target and difficult target. The positions selected for doing the test are illustrated in the Fig. 5.4. Each player will kick the ball 30 times for each position.
In order to randomize the results and avoid repeating, the player will kick five balls in one position and change to other position. At the end of the test, the player has done 30 kicks for each position. Moreover, in order to avoid that the players feel tired after 15 kicks they have to rest from 5 to 10 minutes.
The players have time to get use to were the device and feel comfortable with it.

During one kick and the following one the player can rest during three minutes in a relaxed position, and when he feels ready he kicks the ball.

Once the IZOF of each player is found, the device is ready to send stimuli when the device detects has the physiological state of the player inside the range.

The aim of this test is to verify the device's effectivity during rugby kick training, so the qualitative results of the test using the device will be compared with the ones obtained when the players are without the device working.

Before starting the test players has been coached in order to understand the

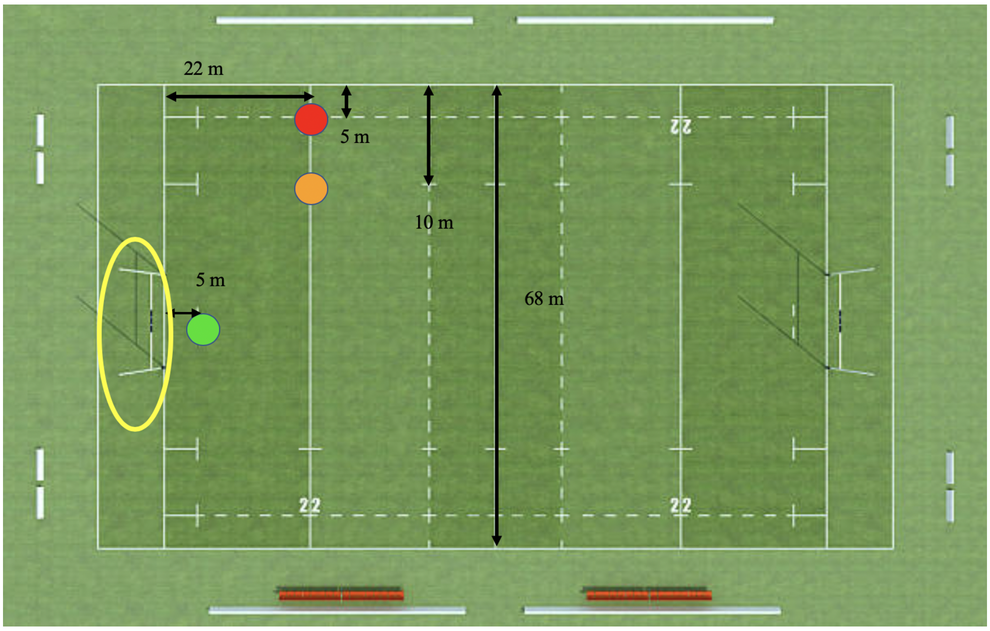

Figure 5.4: Rugby field with the three positions (red difficult, orange moderate and green easy) and the goal marked in yellow.

device functionality and which is the aim of the device. They wore the device before the final test starts to discover the comfortability and to know how it vibrates and understand the timings and procedures. The training time was approximately 10 minutes for each player. This test was performed 1 week after the previous one and the position and resting rules were the same. The qualitative results of the athelte performance were registered in order to compare the to the ones obtained without using the device.

Chapter 6

Results and discussion

Although being composed by few elements, sensing devices are able to perform well, sending the data continuously to the PC, and rarely presenting issues whenever the connection is established. However, it sometimes happens that a Bluetooth module fails to connect. There is no solution in this moment, the solution used was to reboot the computer to establish a new Bluetooth connection. The module Bluetooth connecting Arduino UNO to the PC has not presented the problem.
On the wrist, the device feels a little cumbersome at the beginning, but it is not annoying and definitely does not affect much the movements of the users. The thing that affects more the movements at the beginning were the wires for the sensors. The solution was to attach them to the body. Wearing the device on the wirst will be a problem when performing activities that the hands or arms are the principal part of the movement, as basketball or tennis.

The other very important aspect to evaluate for a system of this kind is the stimuli performance. First of all, it is necessary to underline that continuous tests have been performed throughout the whole development of the system; every major and minor change to the code has been followed by a test in order to understand if and how the system was affected by those variations. It is also necessary to consider the logistic difficulties that a project of this kind carries along: the tests require space and equipped field and ball. The tests are difficult to do in a controlled environments, such as a laboratory.

In order to numerically assess the performance of the system, various test sessions are conducted, involving the six participants performing a series of kicks, divided in two sessions. It was necessary to train, not only the device, also the players. They had to get used to wear the whole device and functioning of it.
The first idea was to use the device during the whole training and during movements. In literature there is not a clear solution for movement during biosignals acquisition (specially for EDA) was found, it is a problem for all the devices that want to record EDA and biosignals in general. Few movements can be filtered, but as less are done is better.
So, the solution was to make the player stay calm between one attempt and the following one.

The test sessions are performed in a simple setup, a rugby field and the players with the ball kicking it. The only problem could be to find a rugby field, but once found no more set up was needed.
The players were asked to perform the same activity twice, once without the device and the other one using the device (with a previous training session). It is relevant to notice that both players involved in this analysis have performed the same acquisition phase, with 30 attempts recorder from three different positions of the field. This means a total of 90 attempts.

In order to decide if the device is selecting well the moments for performance the players did the same test and we evaluate the effectivity of the player compared to the other attempts without the device.The results obtained for the six players are summarised in Table 6.1.

In the results it is possible to see that all the players had improved their efficiency. It is also true that it was necessary to make a training session with less attempts to perform wearing the device. This results show a really good performance of the device, there are players that had improved a lot their efficiency. This can be explained because most hyperactive people when is guided for a device is not as impulsive as they normally are. They tend to control they impulses and think better the action that they are going to do.

	Effectivity without device	**Effectivity with device**
Subject 1	86 %	91%
Subject 2	79 %	83%
Subject 3	68 %	79%
Subject 4	82 %	87%
Subject 5	89 %	91%
Subject 6	88 %	90%

Table 6.1: Comparison between the effectivity of the athletes with or without the device

After the training session for testing the device was done, the participants were asked to answer a poll (appendices) in order to know which is their opinion of the device. The people who answered the survey were the same participants used for the test and five professional coaches, who followed the trainings session. They all had more than 5 years of experience as professionals in rugby. 10 participants were male (90,90%) and 1 female (9,09%). 7 were Spanish (63,63%), 2 Samoan (18,18%), 1 South African (9,09%) and 1 Italian (9,09%).
Regarding their education, 4 coaches and 3 athletes asked to have a master's degree level (63,63%) and the others a high school diploma level (36,36%). All of them (100%) have had a previous experience in training devices such as pulsometer or other fitness devices and with electronic devices.

The results of the poll show that a 100% of the participants were satisfied with the functionality of the device and they think that the device is useful.

Their opinion is that the device is not difficult to use, one of them thinks that the device is neither, difficult nor easy. The 54,54% disagrees in the opinion that the device is difficult to use and the 36,36% strongly disagrees.

Talking about the conformability 8 (only asked to the athletes) of the product the 50% are slightly satisfied with it, the 33,33% moderately satisfied and only the 16,67% is not satisfied with the model. Looking at these results it seems that this is a week point of the device because all the participants vote this with the half score, less and has received the worst possible score.

The training time needed for get used to the device, understand how it works and the timings were rated for the athletes the 100% of the athletes (54,54%) as short and for 4 coaches (36,36%) was defined as neither, long nor short. The other coach (9,09%) rated it as short. So summarizing the (63,63%) thinks that the training time is short and the rest neither, short nor long.

To finish they were asked if they would recommend the device to other professional athletes, coaches or teams. Talking about the athletes 1 of them asked that he would not recommend the device (16,67% of the athletes), two of them neither (33,33% of the athletes) and 3 (66,67% of the athletes) of them that would highly recommend it. Talking about the coaches, 4 of them (80% of the coaches) would highly recommend the device and 1 of them would recommend it. (20% of the coaches). The device would be highly recommended for 7 participants (63,63%), 1 of them would recommend it (9,09%), the 18,18% neither, recommend or not and 1 of them (9,09%) would not recommend it.

The suggestions given by one of the players, the one that said that would not recommend the device is to add different type of feedbacks, in order to not feel a vibration in the arm because this causes nerves to him. An audio feedback would be a good choice for these cases.

Moreover, one suggestion that have been repeated for more than one of the participants is to improve the graphic interface. In order to have a more pleasant and intuitive software. At the end the most suggested thing is to improve the wearability and comfortability of the device. Moreover, also the size can be improved to be more easily adapted to the body. Being a device that have to be used during sports activity and technical movements it is important that it does not disturb the player when he/she is doing the movements.

Chapter 7

Conclusions and future Works

This work can be summarized in three parts: the first is to understand the psychological theories used to explain the relationship between performance and stress, the identification of important physiological signals that can give this information and understand how can be applied. The second is to explain how the device was built and acquire the data and perform the test to understand if the device is working or not. In the third part the results are analysed, and some conclusions are extracted.

The first part of the thesis has been focused on understanding which role play stress, arousal and anxiety in the sports field and how they can affect the performance. It presents an overview of the sports psychology field and in which point it is now. How arousal plays different roles depending on the person.

The following chapter, in fact, has been dedicated to the study of which sensors and DiY technologies will be the best one for the project. Bitalino has been the chosen technology. In this chapter was also explained which biosignals are important to be studied, in this case EDA and ECG. The signal is important but what is more important is to understand what they mean, and for this reason features as SCR and HRV are extracted from them. This features are the most relevant ones to understand the psychological state of the people.

The next part was based in explain the software and hardware part of the device. The flowchart that the device needs to follow in order to function good and achieve the expected results. The core of the thesis is the actual design of the system, both from the point of view of the hardware components, and from the point of view of the software and code needed to handle and analyse the data. A wide analysis of existing products and academic researches performed in the field of biosignals in sport has been carried out, in order to evaluate which solutions have been adopted and which were the problematics that have been faced. For the hardware, a solution based in Bitalino (DiY technology designed for being used with biosignals) and Arduino UNO. This is one of the main problems of the device, chose Arduino UNO, the best solution will be to use a NanoArduino or TinyArduino Are devices used for this kind of wearable devices. This would improve a lot the final result. For what concerns the wireless connectivity, an HC-06 Bluetooth module has been integrated into the device, providing the possibility to directly interface it with a PC and therefore enabling real-time analysis. Also in this chapter the machine learning basics were described. Supervised machine learning has been identified to be the most appropriate category for the kind of system designed in this work, since the training samples can be directly associated to a determined zone of performance.

The following part has been dedicated to the development of the graphic interface done in MATLAB, which can be controlled by the user by means of a simple, functional GUI. This program has to address different problems, especially related to the real-time plotting data or the real-time value of the physiological signal. The program is reading, doing the transfer function and filtering the signal.

After building the application several test were performed. The first two are needed in order to understand the baseline of the user and find the IZOF, in order to understand the psychological state of the user for her/his best performances. These tests are done by teach the device when it has to send the stimuli or not. The final test was performed in order to evaluate the device.

One of the observations which can be done, looking back at the process, once the the Bitalino used during movement does not work properly and that these kinds of devices cannot acquire EDA during movement, it seemed that the device has no sense. However, also if it's strange to think in an athlete without movement it is a good choice. The device is thought in order to be used for specifications during matches, "dead ball actions", which require a lot of calm, concentration and technique. This actions are the ones that require more concentration. As an example it can be a penalty in football, a free hit in ruby or free shot in basketball. In this kind of actions the players have time to think, stop and act, using this device in trainings the player is getting used to find quickly and knowing when they are in the IZOF and achieve the best performance.

The final part of the work has been dedicated to the discussion of the results, which observes the system achieving very satisfying values of effectivity, the players have improved they results obtained without the device. This achievements push to believe that an improvement and extension of the system is possible if further studies will be performed in this field.

The work developed in this thesis represents a great example of a multidisciplinary research activity, as different topics have been approached, studied and merged in order to build a working prototype with interesting potential. Although the results achieved in this work are satisfying, there are still many possibilities of improvements and evolution of a technology of this kind. The objectives for future work on this subject are the following:

1. The possibility to increase the number of feedback given to the athlete. Also customise the stimuli for each user, in other to not stress the person who is performing. As have been learnt in this work which is good for one person is not necessary good for others. Some people get stressed when their wrist is vibrating, so a different kind of feedback would be a good option.
2. The use for other sports and actions.
3. Exploring the capabilities of more advanced components and more appropriate software could lead to an overall improvement and con-

sistency of the performance. For example, better sensors and filtering, in order to better characterise the different situations rapidly. Better application graphics and better wearable device.

4. The possibility to develop an application for improving the shooting adding also movement recognition and tracking the players movements in order to help in both, technical and psychological skills.
5. More compact device in order to improve the comfortability of the device and possibly to use in sports where arms have more importance

In conclusion, a wearable system to detect the psychological state of athletes has been developed and this work represents a first attempt in describing the relationship between arousal and performance. The results obtained show that development of this kind of products is possible. However further research has to be done in order to gain a complete knowledge of the potentialities and the limitations of this technology.

Appendices

Age:	Team Role (Player/Coach):
Years of professional experience in Rugby:	Nationality:

Higher level of education:

- ☐ Secondary Education (High School)
- ☐ Post-Secondary Non-Tertiary Education
- ☐ Bachelor or equivalent level
- ☐ Master of Science or equivalent level
- ☐ Doctoral or equivalent level
- ☐ Others

Are you satisfied with the device functionality?

Extremely satisfied	Very Satisfied	Moderately satisfied	Slightly satisfied	Not satisfied

Is the device difficult to use?

Strongly agree	Agree	Neither, agree or disagree	Disagree	Strongly disagree

Did you feel comfortable wearing the device? (Only for players)

Extremely satisfied	Very Satisfied	Moderately satisfied	Slightly satisfied	Not satisfied

The training period to get used to device is:

Too Long	Long	Neither, long nor short	Short	Too Short

Would you recommend the device to another athletes or coaches?

Strongly agree	Agree	Neither, agree or disagree	Disagree	Strongly disagree

Suggestions and changes (e.g. The feedback vibration, the shape...):

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