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# Sports Science and Human Health

## Different Approaches

*Edited by Daniel Almeida Marinho, Henrique P. Neiva, Christopher P. Johnson and Nawaz Mohamudally*

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# Contents

# Preface

Sports in ancient times were mostly associated with games, entertainment, and competitions. The history of sport across different civilizations and countries has shown how the sports "games" have evolved in terms of structures, resources, and rules, moreover how sports have been used in global challenges through organized sporting activities. Often cited, Baron Pierre de Coubertin's perception of sport is as a basic right and the importance of participating rather than triumphing. His ideas boosted the influence of sports on education and government policies. The impact of sport on morale, motivation, and physical strength was recognized quite early.

However, in this era of high sedentary lifestyles, understanding and promoting the correlation between sport and human health is of paramount importance, be it to improve quality of life or simply as a matter of enhancing productivity within an organization. Thus, sports are multidimensional, are referred to as disciplines and, beyond entertainment, a science. Sports science together with human health and technology are actually the vertices of the same triangle.

"Sports Science and Human Health - Different Approaches" is a compilation of state-of-the-art knowledge about technological developments in sports from diverse perspectives, such as performance management, burnout and stroke detection, and improvement of motor-skills. The readers will be amazed by the adoption of emerging technologies like artificial intelligence, wearable devices, and cloud services in sports matters. Nevertheless, the book also conceals non-technical topics, for example, pertaining to the promotion of peace among nations, and on personal development.

Anyone simply seeking deeper knowledge about Sports Science or looking for research avenues in view of a doctoral study for instance will find in this book some takeaway information. The content is of a very high standard written by authors with different scientific backgrounds and research interests.

The book would have been incomplete without the contributions of the authors, whom we wish to thank heartfully. A vote of thanks too, to the Author Service Manager, Miss Kristina Kardum Cvitan, and the whole IntechOpen team for the achievement of this book project.

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Section 1

# Introduction

Chapter 1

# Introductory Chapter: Rising Interests in Sports Sciences

*Daniel Almeida Marinho and Henrique Pereira Neiva*

## 1. Introduction

Sport became a product of interest in different domains of the current society. Beyond the competition or leisure practice of physical activity, there is a large variety of interests regarding the sports contexts, specifically those with social and economic purposes. Using physical activity and sport, we can develop social values and those that today are linked with emerging market economies. These are nowadays mainly based on the notions of success, progress, and external conformity. There is a clear need for being properly informed and aware of this set of values for the optimal development life in society, benefiting from a clear involvement in sport. The business world has found in sports a new investment path, either through participating in scientific and technological development or by taking advantage of the profitability of the activity itself.

The investment in technological development by specialized companies, in partnership with the sports institutions, ensures continuous development of athletes through the optimization of performance but also ensures more information to those who are spectators. Furthermore, this development also benefits non-competitive activities, with people now being able to follow and monitor their physical activities in real-time. The progress of technological devices leads to the optimization of sports performance, increases the efficiency of the training process, and creates reliable monitoring and increased motivation to practice for the "common" person. The user benefits either by increasing performance or by improved health status. Being seen as a potential of an investment, large companies are looking closely at these areas associated with sports and health, to guaranty better quality of life for all people. Also, this technological development allows for different experiences and contributes to what is called sports tourism. The search for new sensations, different events, and the visit to places that provide different experiences for users, increase the investment of cities and local towns in sports events and the different range of activities. The purpose is to increase tourist interest and investment in local development.

## 2. The technological development

Technology is a resource in constant evolution, which increasingly provides greater utility in almost all activities developed by humans. Sport is no exception. Technology is closely associated with sports and physical activity, offering both new possibilities and improvements in existing activities. The technology allows us to obtain better results in sports performances, optimize training programs, and deepen the knowledge through a reliable and more precise output. It provides a lot of interventions that range from the biomechanical and physiological analysis of performance to the most suitable training plan for each sport or athlete. It will not provide victories, but it will help for sure to improve training efficiency and to maximize performance.

Research has recently been applying technological development to human motor skills, leading to the optimization of motor learning and/or technical corrections. For instance, if we have access to a device that provides feedback regarding the biomechanical analysis of the movement, it can be corrected in real-time and learned efficiently. This is a step forward for all interested people, from competitors to non-competitors, in sport and physical education, from children to adults, opening a wide range of possibilities for sports and health professionals.

## 3. The sport and human health

The example of wearable technology and their incorporation into personal devices allow monitoring movement in several contexts but also it allows us to prevent risky situations for human health. The technological devices are now being developed to monitor health-related signs, such as heart rate variability, respiration rate, body temperature, blood pressure, oxygen saturation, electrocardiogram analysis, and other complex variables such as stress and fatigue index. These offer a possibility of being remoting monitored by health and sports professionals, and by the individual himself. The general purpose is that, during an activity, these portable devices could be used to detect or to predict an anomaly and then provide the alarm to the health professional. All these new and emerging knowledge comprises a lot of issues that should be discussed and alert us for the continuous need to update our knowledge on the emerging technology applied to sports and human health.

The intervention of sports professionals has been benefiting a lot from this development. For example, recently a linear position transducer has been applied to monitor velocity during resistance training in older adults. This allowed us to better control the training load and to monitor progress in each single training session. The use of this kind of technology assumes high relevance in competition, but in older adults, it could be of huge interest. For instance, the research found that they did not need to do usual resistance training volumes (number of repetitions and duration) to obtain the needed strength gains to perform daily activities in a better way and improve well-being. Moreover, this little device when used on daily basis prevents excessive load, allows the adjustment of training loads in each session and according to each person. This results in greater improvements with a low risk of injury. This is only an example of how the development of technology applied to sport and physical activity can be used to improve life quality, in different age ranges and populations.

## 4. The economic interest

In recent years, technological and social developments have dramatically transformed the way most people see time and life. In this context, tourism is going through a phase of deep transformation. More than different places or opportunities for rest, people travel more and more in search of new experiences, that could be associated with different active practices. During this transformation, the transition from tourism in which the objective was to rest, the inactivity, and the abstraction of the real world, to active tourism in which the intention is to experience the greatest amount of remarkable experiences during travel, should be highlighted. The activity in which limits are intended to be experienced is included in the same dynamics of contemporary society, also experiencing a phase of growth and mutation.

The new economic interest might derive from investment in research and development of new technologies. There is a growing market that makes profit by the dissemination and sale of its products to the common user, who practices physical activity, and to the athlete, to optimize performances. Moreover, the new sports tourism, which aims to provide new and remarkable experiences, is also a profit potential. Note that sports tourism also provides, in addition to the sporting activities practiced by tourists, the activities in which the tourist is watching or spectator. So, it is recognized that several commercial brands identified in the emerging sports-related activities a possibility of investment and profit.

## 5. Conclusion

In this chapter, we have pointed out some interests that have been emerging in the field of sports sciences, related to sports performance, physical activity, health, and also the economic component. The latter has been fundamental in today's society and has become increasingly important in the sports context. Technology is increasingly present in the sports world. In terms of highly competitive sports, this reality is more and more frequent. Specialized companies are investing in the development of programs and applications to monitor the most varied sports and physical activities. New trends are now emerging in the interest of the economic market, namely applied to health and the context of tourism. Technological development has led to the rapid growth of several areas of interest in which the common link between them is the sport, as a tool for human development in today's society.

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Section 2

# Sport and Human Health

Chapter 2

# Sports as a Mechanism for Reaching Your Potential: The Relationship between Positive Psychology and Sports

*Christopher Johnson*

## Abstract

People have been searching for the good life or personal well-being since the ancient Greeks. During this same period, people have been expressing themselves through sport, participating in games of athleticism as a means of discovering who they are and reaching their potential. This chapter examines the relationship between sports and a flourishing life. By examining sports as a mechanism of achieving specific traits of positive psychology associated with flourishing, the researcher is able to determine that sports are a matrix in which human potential can be nourished.

**Keywords:** sports, well-being, flourishing, potential, health

## 1. What is flourishing?

Flourishing is the pinnacle of human potential. Sometimes referred to as self-actualization, excellence, well-being, or happiness, a flourishing life is what people strive to attain. Flourishing is an optimal human functioning. It occurs when an individual fits their environment so they can function more efficiently and effectively. Fitness is a sport-related term regarding how well individuals fit their environment. When it's a good fit, individuals are more able to overcome resistance, hence why the term fitness has been adopted by resistance training athletes. When an individual's fitness is poor, they are not adequately fit for their environment and will have more difficulty facing resistance or adversity.

An individual's fitness is relevant for every aspect of life and easily identifiable in sports. For instance, some athletes are naturally better at power sports, and some are better at endurance sports. When an athlete identifies their innate abilities, if they participate in sports highlighting those abilities, they will be a better fit and reach a higher potential. Flourishing is significantly influenced by how well an individual understands themselves and their situation.

If you go back to the time of the ancient Greeks, the philosopher Aristotle (384–322 BCE) believed that Eudaimonic well-being or engaging in something of value, a long-term investment rather than short-term pleasure, fulfills our potential. Aristotle believed we should do things worth doing, and when we act in such a manner, we may flourish [1]. Things worth doing are opportunities in alignment with our values. Values are deeply held beliefs that establish our character. When an individual lives in accordance with their values, they fit their environment, they are being their authentic self. Their life is in order and they have a set objective that makes sense for them. Living in this manner is often referred to as living with a purpose.

For the reason that flourishing is specific to the individual, it is considered subjective, i.e., your well-being is specific to you and your needs, it is not a universal constant [1, 2]. What works for you, may not work for anyone else and vice versa. This concept is known as subjective well-being (SWB) and is understood as your life satisfaction is the result of all your positive emotions minus your negative emotions:

$$Ep - En = S \tag{1}$$

How you interpret your emotions and come to your unique conclusion is determined by your uniqueness as an individual and how you react as an individual to social and environmental situations. In other words, according to SWB, your well-being is idiosyncratic.

If flourishing is indeed a subjective measure of how well we strive toward things worth doing, then the activities we fill our days with should be purposefully aimed at self-improvement. The argument presented in this chapter is sport is an activity that provides opportunity to invest in developing traits that enrich well-being, and although sports may seem to be a pastime, sports are actually a breeding ground for human flourishing.

The remainder of this chapter will examine three concepts of positive psychology associated with flourishing through the lens of sport in an attempt to highlight the value of engaging in sport as a mechanism for reaching human potential.

### 1.1 Positive psychology and human potential via sport

Sports have deep roots in personal development. The word sport evolved out of the word disport, which is the combination of dis- meaning *away* or *depart* and portare, meaning *carry*. Sport means to carry away from something or break apart (de- and part) from it. Sports, from a philosophical perspective, carry people away from their current sense of self so they can break apart from it then rebuild stronger. Similar to the etymology of sport, the word exercise which is a subdiscipline of sports originated from ex- meaning *out of* and arcere meaning *constraint*. In other words, exercise means to remove our constraints or liberate the body from itself.

Sport and self-improvement are innately linked. Specifically, as a means of replacing our old self with an evolved version through physical effort. During sport, people are burning off their old self through sweat and hard work and replacing it with a stronger body and mind as we adapt to the stimulus. This scientific principle is represented in mythology as the symbolic phoenix burning to ashes in flames and being reborn stronger. Prior to the scientific method, storytelling was the primary way of explaining the world. Powerful stories such as the phoenix stick with us through the generations because they metaphorically represent what individuals are going through. The phoenix is a symbol that athletes enact as they chase their potential, burn off their weaker self, and replace it with a stronger being through sports.

In this chapter, we will examine three concepts of positive psychology that are associated with human potential and flourishing through the lens of sport. These concepts are PERMA, self-determination theory, and core self-evaluation theory [1, 3]. We will then examine underlying denominators between the concepts and discuss a generalized concept for extracting potential out of sport.

## 2. Sports and PERMA

One of the founding fathers of positive psychology, Martin Seligman, in his book *Flourish*, shares a model for flourishing known as PERMA. PERMA is an acronym capturing what Seligman deems to be the five components of human flourishing, positive emotion, engagement, relationships, meaning, and accomplishment [4] (**Figure 1**).

Sports are a catalyst for action. With sports ranging from soccer, rock-climbing, darts, and e-sports, sports are as diverse as the people participating in them. With that said, sports are a means by which people voluntarily create, problem solve, and act within a boundary of agreed upon rules and receive feedback as a result of those actions. This deems sports as an appropriate mechanism to measure the five elements of PERMA.

Uusiautti et al. [5], in an attempt to find a solution to the problem of boys' decline in success and engagement in schoolwork in Finland, examined the implications of sport as a method of increasing the five components of PERMA. Their findings suggest that sports do indeed increase the traits of PERMA and thus well-being. The researchers' aim is by increasing the young males' well-being; the boys will be positive contributors to their families, communities, and society. Using PERMA as a lens by which we can analyze sports' contribution to human well-being is a justifiable means of acknowledging the correlation between sports and human potential [6].

### 2.1 Positive emotions and sports

Positive emotions have been shown to broaden the scope of attention and cognition which increases well-being [7]. These findings are reason to invest in activities that stimulate positive emotions. Sports activate your entire spectrum of emotions. When athletes deem a stressor as within their ability and an opportunity for growth, positive emotions follow. As athletes develop their skills and participate at a level of competition appropriate for their current ability, they will eventually see progress, and positive emotions will arise from seeing an improvement in their sport.

There is a saying, "no one has ever felt bad after a workout." This axiom although anecdotal is a remark regarding the satisfaction people have after engaging in something as physically demanding as sport. People who create a lifestyle involving higher


**Figure 1.**
*PERMA image.*

frequency of physical activity boost psychological well-being [8]. When people exercise beyond the weekly recommended number of moderate to vigorous activity minutes, they flourish and have positive affect, and their autonomy needs are met [9]. In other words, vigorous exercise produces a favorable emotional state [10].

### 2.2 Engagement and sports

Engagement or flow is the process of being fully engulfed by the activity. It is described as a state of optimal experience [11]. Athletes commonly find themselves deeply engaged in their sport to the extent that nothing beyond the moment matters. Engagement in sports is often described as "being in the zone." Engagement occurs when the following characteristics are met [1]:

1. An athlete feels challenged, yet capable of meeting the demands of the challenge.

2. There are clearly defined goals with immediate feedback concerning those goals.

3. The athlete feels engulfed by the activity; they are one with it.

4. The concept of time is lost.

5. They do not feel self-conscious.

6. There is no concern for failing, the athlete is in control.

7. The activity is rewarding in itself.

An athlete must find harmony between their challenge and skills if they want to be engaged. The sport needs to be highly challenging, yet the athlete must have the skills to match. The challenge should be slightly more difficult than what they are used to accomplishing. If the challenge is too far beyond their current skills, the athlete will feel anxious and stressed. If this occurs, the athlete must increase their skill or participate against a lower-level challenge until they reach the skill level appropriate to achieve flow at a higher level [1].

When athletes achieve this optimal state of engagement, they are in a state of mindfulness, when the only thing that matters is the moment and time ceases to exist. On top of scientific literature backing up the benefit of engagement and performance or well-being, philosophical schools of thought such as Buddhism and Stoicism support an idea of living in the moment as a corner stone of living "a good life" or a life worth living. The philosophy of yoga has a saying that the only sin is boredom, because we are not living in order with the universe. In other words, when we are engaged, life is more fulfilling.

### 2.3 Relationships and sport

Relationships are a fundamental aspect of human flourishing [12, 13]. Team sports (baseball, soccer, lacrosse, basketball, etc.) are opportunities for people to develop relationships that may lead to well-being. Healthy relationships are ones in which people feel challenged yet safe to express themselves and go after those challenges without ridicule. This is a good description of a healthy sports team. A good teammate pushes you to rise to and face obstacles and supports you during setbacks.

A good coach or teammate is an excellent resource for developing relationships. Research shows that engaging in developmentally appropriate team sports helps protect health-related quality of life at every age [14]. The matrix that is sport cultivates opportunities for relationships such as these to manifest.

Sport is also an excellent means of establishing or strengthening an individual's relationship with nature. Nature has been shown to increase well-being by improving physiological and mental health [15, 16]. Many sports are performed outdoors, some of which are performed directly in nature. For some people, this may be the only time they spend in nature and thus their only opportunity to improve their physiological and mental health through nature.

### 2.4 Meaning and sport

Meaning, purpose, and fulfillment are a core aspect of Eudaimonic or a long-term aim at well-being. Purpose or a goal provides meaning to life, and when we act out that meaning toward achieving our goal and are successful, we feel fulfilled. Sport provides purpose, meaning, and fulfillment by providing people with a foundation from which to build upon via rules by which people need to operate under if they want to be successful. Rules often get a bad reputation as boring, but rules provide the structure by which progress happens. Without the direction and guidance of rules, a problem is not clearly identified, and thus, you cannot have a clearly defined aim.

For instance, being a successful free solo rock climber bases its foundation in being strong and lean and having high muscular endurance and low body fat percentage. This foundation may act as the base of a successful free solo rock climber's life. Everything they do may center around this purpose, and if they fall short, the results may cost them their life. It is for this reason that strict adherence to the rules of the sport provide a direct purpose or foundation by which to live by and meaning or guidance that must be followed for fulfillment to be achieved. Foundations such as this example provide a sense of direction to set goals and aim. This aim gives an athlete meaning to an otherwise potentially undirected life.

Athletes gain meaning and fulfillment from the act of learning their craft and developing their skills. Athletes are motivated to participate in their sport because it promotes positive experiences, which may lead to well-being [17]. The act of pursuing goals, not the achievement at the end, is meaning. In other words, the feedback from progressing toward their purpose provides the substance people need to live meaningfully more than a trophy. Sport by nature of providing a problem within the agreed upon rules or limitations grants a worthwhile quality to life through the act of attempting to solve those problems within the provided confines.

Sports are similar to a word problem in the sense that word problems are meant to teach you how to interpret a problem and answer it and then apply that same problem-solving process to the rest of life. Word problems are not about memorizing formulas and regurgitating answers, they are about recognizing problems then deciding which solution to apply in order to solve it. Sports offer problems as opportunities to learn how to problem solve in areas outside of sport. There is fulfillment in solving your own problems.

### 2.5 Accomplishment and sport

An achievement is an external reward, such as a trophy, graduate degree, or raise at work, whereas an accomplishment is an intrinsic process that is fulfilling in its own right [1]. An accomplishment is a successful journey or process people undergo in order to reach an achievement. Training hard over the course of a season is an accomplishment, whereas winning the championship is an achievement. Sticking to a resistance training program for a year is an accomplishment, whereas gaining your goal physique is an achievement.

Research shows that intrinsic motivation is generally more preferable than extrinsic motivation. Seligman's theory suggest that accomplishment is the result of our skill multiplied by our effort. In other words, it is not only how skilled we are, but how we apply those skills [1, 4]. Skill and effort according to Seligman are the byproduct of the speed at which we can think, i.e., we can make choices quickly, as well as the rate at which we can learn, providing us with more knowledge and thus experiences from which to quickly develop solutions to problems [1].

Sports are games in which participants are faced with problems, and in most sports, the goal is to outthink then outact your opponent in order to score a point. Your opponent is the problem or challenge, and you must apply your skills and effort by thinking quickly and having a vast knowledge base from which to draw upon in order to win. If you accomplish this more than your opponent, then you accomplish the goal of the sport. This process is an intrinsic skill you can apply to areas outside of sport.

Accomplishment entails progress toward a goal. A goal is an individual's aim. The very word goal has been adopted by sports as its main objective. American football, soccer, basketball, field hockey, ice hockey, and lacrosse players among other athletes are all attempting to score a goal. They are aiming at something, and if they hit their mark, they are accomplished through the effort and skill that brought them to that point.

Sports by nature always entail a feedback system in the form of a score. Scoreboards and team rankings are indicators of a team's progress toward their goal. Individual sports such as track and field or swimming keep documentation of personal records also known as personal best as feedback of athletes' progress. People need feedback to ensure them they are making progress toward their goal.

It is not the goal itself that grants an individual accomplishment, the goal is the achievement. Accomplishment is in the process of what it takes to develop as an individual or team in order to reach that goal. The accomplishment is the progress toward your potential. Sport is an area in which that progress may be developed.

## 3. Sports and self-determination theory of human motivation and behavior

Similar to PERMA's five elements of well-being, Richard Ryan and Edward Deci's self-determination theory is not about achieving an overarching goal; rather ensuring three needs are met while pursuing a goal [13]. Self-determination theory is a process and an accomplishment. These three needs are:

1. Control (autonomy)

2. Competence

3. Connection (relationships)

People must feel in control of their life also known as self-agency, be competent in their craft, and connected or related to people and a purpose beyond themselves (**Figure 2**).

Mallia et al. [18] researched two groups of athletes to determine if the factors of self-determination theory can predict antisocial behavior in young athletes. The

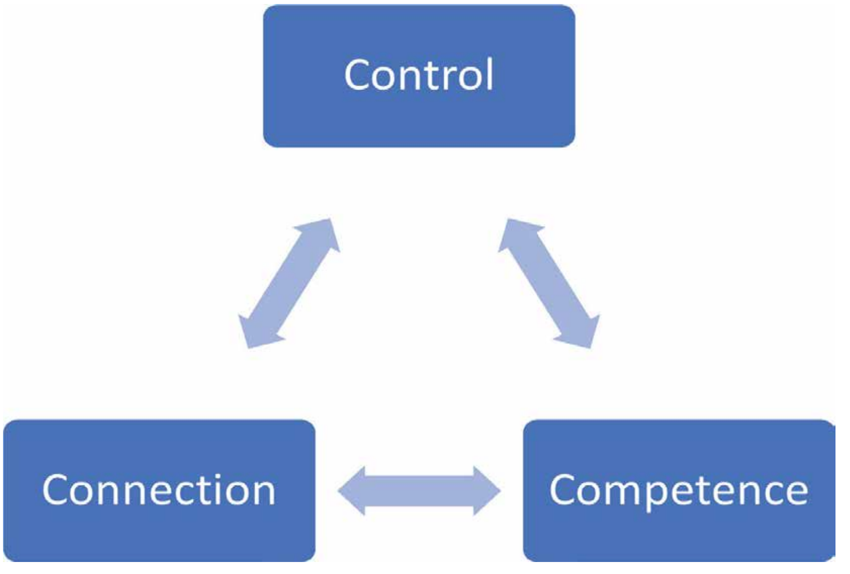


**Figure 2.**
*Self-determination theory image.*

researchers divided 651 athletes into two samples. Sample one consisted of young team sport athletes (N = 355) and sample two was composed of male futsal players (N = 296). Both samples completed a self-report of self-determination theory. Sample two completed two additional measures:

1. Self-reported number of yellow cards received during competition during the last 6 months

2. The number of yellow cards received from referees in the subsequent 2 months from competition records

The results found a relationship between psychological need satisfaction and self-determination motivation and athletes' moral attitudes in both samples. Sample two indicated attitude toward antisocial behavior predicted athletes' subsequent rule violations. Findings suggest that promoting factors of self-determination theory may foster attitudes toward prosocial behavior and minimize rule transgression in young athletes.

Findings such as the ones in the above study support the notion that self-determination theory is a significant contributor to well-being. Furthermore, sport is an environment in which the factors of self-determination theory effect the attitude of an individual. It is for this reason that the researcher investigated the three factors of self-determination theory as they relate to sport.

### 3.1 Control and sport

People need to be self-governing or in control of their lives in order to flourish. People do not feel safe enough to attempt at a goal and potentially develop as an individual if they do not feel they are in control of their life. When people feel the situation is under control, they feel less anxious and are more willing to act. People who feel in control of their situation experience more positive emotions and are more likely to perform to their potential [19].

When it comes to growth mindsets versus fixed mindsets, whereas people with a growth mindset believe they can increase the quality of their life through effort, people with a fixed mindset believe that they cannot improve their state and thus fear applying themselves out of concern that their abilities may be questioned [20]. Fixed mindset people live in fear that they cannot control the destiny of their life, which decreases their ability to flourish.

Sports are games and games need to be voluntary [21]. Thus, by choosing to participate in sport, the athlete has autonomy over their life. Enrolling children in a variety of sports during youth aids in their development and exposes them to options from which they can choose when they are older [14]. The ability for an individual to choose the sport that best fits them not only leads to greater long-term success, but it provides a sense of control to the athlete's life [22].

Sport is a voluntary controlled environment in which people can experiment and grow their mindset without repercussions beyond which they are willing to accept. By participating in sports that are the appropriate level of challenge for their ability, people can learn that when they apply themselves, they can control the outcome of a situation by mastering the skills of that situation.

### 3.2 Competence and sport

Competence is an individual's ability to accomplish a task. By learning the skills of a sport through trial and error as well as observing and mimicking peers, coaches, and elites, athletes grow more competent. This competence in turn feeds back into their control over the situation. People need to feel competent and effective for a healthier personality [23].

Research shows that strong athletic teams and strong individual athletes are predictors of flourishing [24]. By developing an athlete's competence, you are making them a stronger competitor. Stronger competitors are competent in their craft as a result of feedback from their accomplishments. This feedback system of growing more competent in the face of adversity strengthens an athlete's belief in themselves as well as their team (if their team is also competent). The success people experience in one area is the only reason to apply themselves in other areas.

### 3.3 Connection and sport

Connection as with relationships is a fundamental aspect of flourishing. All mammals are shaped by their environment, social bonds included. People need to feel connected to others and secure in their relationship while maintaining their autonomy for healthy well-being [25].

Being on an appropriate sports team and training with a coach who is a good fit for their competence and personality meets this need. The sport and team an athlete is part of is one aspect of their overall environment. Healthy connections in sport can proliferate into other areas of life. The social skills an athlete develops in sport do not have to end when the game ends; these social skills can be put to use in family, friend, and work settings.

People are social by nature; they need to feel connected and related to other individuals as well as a group [25]. The matrix of sport nourishes these relationships by providing a foundation or unified purpose by which teammates can connect. Athletes are not just connecting to each other but to the sport as a whole. By connecting to the sport as something beyond themselves, athletes are transcending, which is considered the pinnacle of self-actualization [26].

## 4. Sports and the core self-evaluations

When it comes to satisfaction at work, four traits were found to contribute to higher levels of satisfaction. These four traits are self-worth, self-efficacy, locus of control, and neuroticism (emotional stability) [3] (**Figure 3**).

Self-worth, locus of control, and neuroticism are the three most studied traits in psychology. Self-efficacy is not far behind in terms of being associated with well-being [27]. In a study by Lopez et al. [28], the researchers examined the relationship between the core self-evaluations and abusive leaders. Upon analyzing the results of 67 participants, the researchers determined that "higher levels of core-self evaluations buffer abusive leaders." With that said, they remind readers that abusive leaders are not a recommended method of increasing core self-evaluations. These results support the recommendation that the four traits associated with core self-evaluations make an individual more resilient. Furthermore, as with PERMA and self-determination theory, they are often associated with flourishing and well-being and for that reason will be examined under the lens of sport.

### 4.1 Self-efficacy and sport

Self-efficacy is a person's belief in their ability to produce a desired effect [29]. When athletes are challenged in sport and their competency meets the demands of their adversity, they are successful, and their self-efficacy increases in response to their success. This process in turn develops belief in themselves that they can successfully and efficiently accomplish future similar task. In simpler terms, if an athlete purposefully practices, they will improve and believe in their ability to perform well in the future. The notion of "I can do this," when confronted with a new challenge, is essential for a willingness to engage in novel task where potential resides. This believe in one's self is self-efficacy and is crucial to engaging in potential developing situations.

Sports provide ample opportunity for people to engage in activities where they are challenged at the appropriate intensity for their skill level. Thus giving athletes

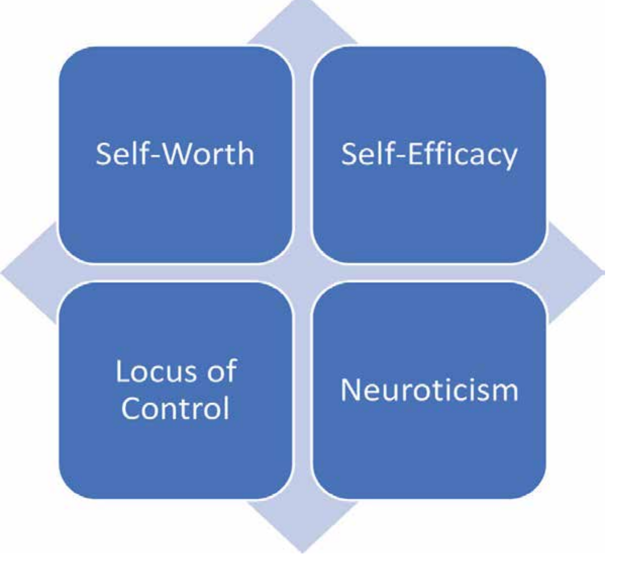


**Figure 3.**
*Core self-evaluations image.*

opportunities to rise to challenges and overcome them. This act of facing adversity and overcoming it develops self-efficacy and moves athlete's one step closer to their potential. In the words of Michael Jordan, "obstacles don't have to stop you. If you run into a wall, don't turn around and give up. Figure out how to climb it, go through it, or work around it." Sports allow for skills to develop in a safe environment through trial and error. That is the essence of practice, to try, fail, adapt, and try again until successful. Every sport entails practice; it's an opportunity for growth. Once people understand that they can develop skills in one area, there is no reason to believe they cannot develop skills in another area outside of sport.

### 4.2 Self-worth and sport

People need to feel connected to something beyond themselves [25]. For some people, this connection to something beyond themselves may be the military, favorite charity, or their local church, and for others it may be their sport. According to Abraham Maslow, self-actualization involves transcendence or being part of something bigger than themselves [12]. Turn on a television or visit a news website and you are bound to see a sporting event or sports talk show. Sport is a means by which people transcend beyond themselves and achieve self-worth by associating with a group. In the United States of America, sports have reached an ideological level of worship by some fans and participants [30]. People constantly attend sporting events by the thousands dressed in face paint holding giant posters, screaming in support of their team in freezing weather. Fans sacrifice their time and comfort for their team, and if their team wins, they associate the victory with their contribution of support.

When people are provided with the opportunity to participate in an activity that challenges their current skills and demands that they adapt in order to be successful, you are providing them an opportunity to self-actualize. People's self-worth or self-esteem as it is sometimes referred is a self-evaluation of an individual's worth. People need to feel their efforts influence the world and that they make a difference. High self-worth is a predictor of success in many areas from school, happiness, marriage, relationships, and criminal behavior [31–33].

### 4.3 Locus of control and sport

Victor Frankel in his book *Man's Search for Meaning* suggested that it would be a good idea to have a Statue of Responsibility on the West Coast of the United States since there is a Statue of Liberty on the east coast [34].

> *Freedom, however, is not the last word. Freedom is only part of the story and half of the truth. Freedom is but the negative aspect of the whole phenomenon whose positive aspect is responsibleness. In fact, freedom is in danger of degenerating into mere arbitrariness unless it is lived in terms of responsibleness. That is why I recommend that the Statue of Liberty on the East Coast be supplemented by a Statue of Responsibility on the West Coast.*

Frankel's point is that freedom and responsibility go hand in hand. If an individual does not take responsibility for their actions, soon all of the foundations which their freedoms are built will crumble. Furthermore, it is not freedom people should crave, rather the responsibleness that is the positive aspect of the balance of society. People should be proud to take on responsibilities and contribute to their society rather than prioritizing freedoms over responsibility.

An internal locus of control is the idea that the outcome of an individual's life is their responsibility. On the extreme end of sports, if a free diver is not responsible and invest in becoming a master of their craft, it could cost them their life. On the flip side, if the free diver invests in the years of skill development and effort, freedom to accomplish what few people can fathom is possible.

On a smaller scale, if a soccer or basketball player invest in developing their skills, the athlete will successfully score more points than someone who does not take responsibility and practice their craft. If the athlete does not take responsibility for mastering their craft, they will not progress as rapidly, and their progress may diminish. Taking natural talent into account, people who deliberately practice their craft catch up to and surpass those who have natural talent at a young age yet do not invest in developing that talent [22].

Either outcome is the athlete's choice. If an athlete desires to progress their career, they must take responsibility for developing their skills. As an athlete develops their skills, they will feel more competent in their sport and feel more in control of the outcome, which in turn also increases self-esteem. The result begins with taking responsibility of their life.

As an athlete's ability and success rate increase, they are controlling their life by producing a desired outcome. The athlete is proving to themselves that when they take responsibility for their actions, they have greater control over their life's direction. When an athlete feels they are in control of their life, they can trust the process because based on previous experience, it should provide a predictable outcome. Trusting the process allows people to not have to worry about the unexpected, which allows them to be more present in the moment, also known as mindfulness, a concept shown to have a positive relationship with self-actualizers [35].

### 4.4 Neuroticism and sport

Neuroticism is an individual's emotional stability or moodiness. Neuroticism is negatively correlated with emotional stability. In other words, highly neurotic people have lower emotional stability. Research by Judge et al. look to find a common factor between self-efficacy, self-worth, locus of control, and neuroticism. The researchers conclude that neuroticism is the common denominator [27]. People who experience emotional stability also experience increased self-efficacy, self-worth, and locus of control.

As mentioned, sports are a mechanism that may increase self-efficacy, self-worth, and locus of control. Increases in these areas may decrease neuroticism. Research shows benefits of exercise, physical activity, and sport for well-being [36], as well as exercise being performed in nature having a positive effect on public health [16]. Furthermore, research shows that sports can encourage the development of psychological factors that could aid in emotional stability [37]. In other words, by improving your environment, it may improve your emotional stability. These findings are indicative of your environment influencing your well-being. Sports are a microcosm in which those positive influences can develop.

## 5. When potential is not reached

What happens when people do not reach their potential? Individuals can still be successful when they do not reach their potential. The difference between success and flourishing is fit. As mentioned earlier, fitness is more than an exercise physiology term. Fitness is how well an individual fit's their environment. It's their ability to meet the required demands of the situation. Fitness training during sport is doing just that, making an individual more fit or better equipped for their sport.

Although training is part of success. The most successful athletes are the ones participating in sports that are physiologically fitted for them. For instance, the muscle physiology of a professional weightlifter and professional marathoner is on opposite ends of the spectrum. The former is primarily fast twitch muscle fibers, and the latter is primarily slow twitch muscle fibers. By participating in the sport that matches their physiology, they became professional (with effort, time, and resources), yet those equivalent results are less likely if the same two athletes switched sports. The athletes may see some success, but they would no longer be participating in the sport that is the best fit for their unique physiology and may not reach their potential.

In order for an individual to flourish, they should aim their efforts at a goal in which their uniqueness matches their environment. In other words, do what you love, what you are innately drawn to, not only what provides financial success and recognition. A Harvard Business Review article by Robert Kaplan [38] focuses on this problem of successful, ambitious, and talented individuals he has taught and coached in management and MBA programs at the Harvard Business School who express deep frustration with their careers. Kaplan mentions a similar problem in that many of these individuals are not doing what they really enjoy. They are successful, but they may be more successful and happier if they apply their efforts to something more meaningful to them.

These individuals Kaplan is referring to are successful. The question is, are they as successful or as happy as they could be? They may be successful, but are they flourishing? If they invested in finding their best fit, would they reach a higher potential? Sports, through trial and error, teach athletes how to test new experiences and see if they are the right fit for us. Sports provide an opportunity to teach us who we are. By participating in an array of sports, we learn how to identify what best fits our uniqueness as individuals. This skill set is applicable for all aspects of life from professional to personal.

## 6. Discussion

PERMA, self-determination theory, and the core self-evaluations are after closer examination, variations of similar concepts which when met have been shown to increase human flourishing. Each theory may be wording their concepts slightly differently, but they are all searching for a similar result. Flourishing occurs when people voluntarily engage in appropriate challenges and see those challenges as opportunities for growth and are supported during their endeavor.

After examination, the researcher suggests a similar model which he refers to as the sport potential model (SPM). SPM consists of two concepts of sport which may be applied to areas beyond sport. These two concepts result in a process by which all of the traits of PERMA, self-determination theory, and core self-evaluations may be experienced. The following is a deeper look into the two concepts:

1. Fitness: fitness is the degree to which individuals fit their environment. It's an athlete's ability to adapt to and meet the demands of the sport. Fitness can be thought of as internal resources. The better fit someone is to their environment, the more likely they are to be successful in that environment.

2. Play: a play entails two things, a plan and a player. When athletes perform a play, they are acting upon their ambitions. Players are aiming at a goal and striving for that goal under agreed upon rules with consequences. To play a game well, an individual must play their strengths to the situation while avoiding their weaknesses. The better fit a person is for the play, the higher their likelihood of success. The less fit an individual is for a play, the more resistance they will encounter.

If the two concepts of SPM are in harmony, the game is more likely to go as planned, and athletes will experience most of the traits listed in **Figure 4**. If this process repeats itself overtime, the athlete may reach their potential.

A flourishing individual is more than one with many achievements; it is someone who is able to locate themselves as a node in a web of relationships. Sports are microcosms for testing and discovering our fitness or our relationship to the larger game. It is also worth mentioning that it is not a single game that matters, rather the series of games or overall tournament, i.e., life. To expand upon an old sports saying, "it's not whether you win or lose that matters, it's how you play the game," a single outcome does not matter; rather it is the interaction of all the outcomes combined that determine how well you are doing. In other words, it's in the process that

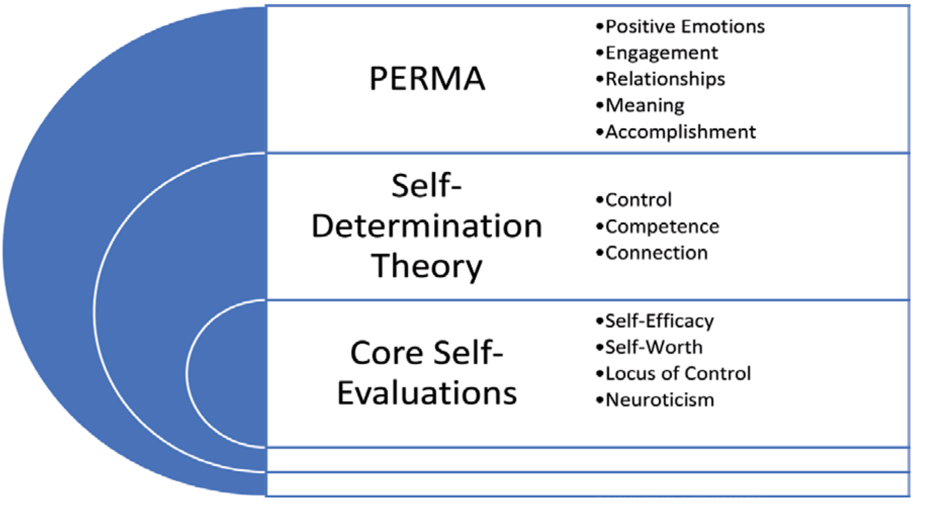


**Figure 4.**
*Flourishing image.*

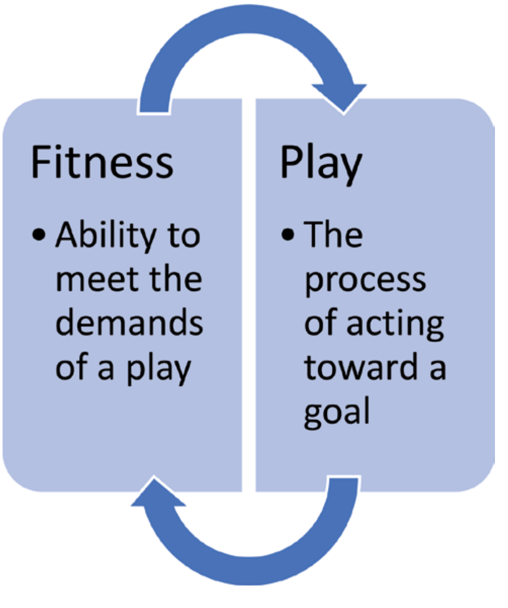


**Figure 5.**
*Sport potential model image.*

you reach your potential. Living by a poor process limits your ability to be invited back and play the game; living in accordance with the rules of the game will get you further in the long run (**Figure 5**).

## 7. Conclusions

In closing, sport is a simulation of life representative of the grander experiment that is "life's the big tournament" or all the smaller interactions interacting to produce our overall experience. In other words, sports are practice for the "real-world." Within the limited reality of sport, people can develop traits that have been shown to improve well-being and bring them closer to their potential. There is ample evidence that the abovementioned traits associated with PERMA, self-determination theory, and the core self-evaluation theory can all be developed through sport and the sport potential model then applied elsewhere to enhance people's quality of life in other areas. It is for this reason that the researcher highly recommends sport as a mechanism for personal development and reaching human potential.

## Conflict of interest

None.

## Thanks

Thanks to Noah Johnson for sparking my interest in flourishing.

## Appendices and nomenclature

None.

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Chapter 3

# Sport for Development and Peace: Current Perspectives of Research

*Tegwen Gadais*

## Abstract

Sport for Development and Peace (SDP) is an international movement that began in the 2000s with the Millennium Development Goals (2000–2015) and is currently continuing around the United Nations' Sustainable Development Goals 2015–2030, driven by international organizations such as UNESCO. Often located in an international development context, organizations and associations use sport as a vehicle to reach several social and humanitarian missions (e.g., education, social cohesion, health, reintegration, diplomacy, and peace). This chapter presents the origins and objectives of the SDP, but it also looks at current research in the field. Since 2010, studies have significantly increased in the field around four main areas (macrosociological, field explorations, program management and evaluation, and literature reviews). This chapter also provides illustrations of SDP research projects, axis of tensions between practice and theory, and perspectives for future research in the field.

**Keywords:** sport for development, sport for peace, sport for education, sport for health, international

## 1. Introduction

Sport for Development and Peace (SDP) is an international movement that began in the 2000s to meet the Millennium Development Goals (2000–2015). Several local, regional, national and international organizations are currently continuing to implement sports projects in an international development context to reach the United Nations' sustainable development goals (2015–2030).

This chapter aims to present the various origins and objectives that are being used around the SDP. It then focuses on current research on SDP, providing illustrations of research projects conducted in the field. Finally, this chapter offers perspectives for future research in this domain.

### 1.1 Origins and history of the SDP movement

Sport for Development and Peace (SDP) is not a new phenomenon contrary to what one might think. In 1894, Pierre de Coubertin had already considered the reconstruction of the modern Olympic Games to bring nations closer together around sports disciplines. He said "I remained convinced that sport is one of the most forceful elements of peace and I am confident in its future action" [1]. But the use of sport to serve development, peace, or diplomatic interests in the contemporary world is more due to the work of Mandela, who said "Sport has the power to change the world. It has the power to inspire, it has the power to unite people in a way that little else does" [2]. Indeed, the South African leader decided to use the power of sport during the 1995 Rugby World Cup to fight apartheid and unite the South African people. According to him, "Sport can create hope, where once there was only despair. It is more powerful than governments in breaking down racial barriers" [2].

The United Nations (UN) took a step further toward the recognition of sport and its diplomatic, integrative, educational, or peace-building potential by signing a resolution in favor of the use of sport as a tool for development and peace-building among peoples, which was adopted by the UN General Assembly in 2003. This vote also led to the reaffirmation in 2015 of the 1978 UNESCO International Charter for Physical Education and Sport. The prevalence of SDP projects was so high that the UN has recognized its potential by setting up a specific instance between 2008 and 2017 (United Nations Office for Sport and Development and Peace; UNOSDP) through which it has initiated a large number of projects, particularly in Central America and West Africa [3]. This office had three main roles: to encourage dialogue, to establish SDP collaborations and partnerships, and to support international sports organizations, civil society, private sector, and media.

### 1.2 Definition and objectives of the SDP

SDP projects have been developing in recent years around the world. They have been defined as "the intentional use of sport, physical activity and play to achieve specific development objectives in low- and middle-income countries and disadvantaged communities in high-income areas" [4], which includes "all forms of physical activity that contribute to physical fitness, mental well-being and social interaction, such as play, recreation, organized or competitive sport, indigenous sports and games" [4, 5]. These definitions have since been widely used by many SDP actors and several researchers [5–7].

In these initiatives, sport is presented as a lever for integration or social reintegration in developing countries or in conflict-affected areas [7, 8]. For example, soccer matches are used between two enemy sides to help rebuild relationships. In addition to its positive impact on health, sport is now recognized for having a number of other benefits such as the prevention of violence or doping, awareness of diseases such as HIV/AIDS, and also as a medium for instilling respect for opponents and rules, teamwork, sportsmanship, determination, and discipline, in youth [7, 8]. These fundamental principles could also be transferred to the social life of person according to some organizations that value them [9]. The UNOSDP [10] indicates other elements related to the use of sport as a lever for development and peace, among others:

a. Sport is a powerful tool with unique power to attract, mobilize, and inspire;

b. Sport embodies issues of participation, inclusion, and citizenship by its very own nature;

c. It represents human values such as respect for the opponent, acceptance of restrictive rules, teamwork, and equity;

d. Sport is used in a very wide range of situations to serve development and peace-building as an integrated instrument in short-term emergency humanitarian aid activities or in long-term development cooperation projects [11, 12].

Finally, sport has benefits such as individual development, health promotion and disease prevention, gender equality, social integration, peace-building or conflict prevention/resolution and post-disaster/trauma assistance [13, 14]. UNESCO published a report in 2016 on the power of the values of sport that reinforces this vision, and then UNOSDP published a document that shows the articulation of using sport to support each of the new Sustainable Development Goals 2015–2030 [10]. From a development perspective, the focus is most of the time on mass sport and not elite sport [15, 16]. In a development context, sport generally includes a wide range of activities adapted to people of all ages and abilities, with an emphasis on the positive values of sport [10]. Sport is used to reach the most needy, including refugees; child soldiers; victims of conflict and natural disasters; poor people; people with disabilities; and victims of racism, stigma, and discrimination [14, 17, 18].

## 2. Current researches on SDP

Beyond descriptions of SDP programs and contributions from international organizations, researchers examined the SDP field and analyze the benefits of these programs on individual development, health promotion and disease prevention, gender equality promotion, social integration, peace-building or conflict prevention and resolution, and assistance after a disaster or trauma, among others [13, 14]. At the moment, four main types of research that have been conducted around SDP can be identified: (1) macrosociological studies on the positive attributes of SDP; (2) exploratory field and case studies; (3) studies on the management and evaluation of SDP programs; and (4) literature reviews on SDP.

### 2.1 Macrosociological studies on the SDP

First, researchers are conducting a large number of macrosociological studies to question the so-called positive attributes of sport by raising its potential abuses [11, 12, 19–21]. For example, Kidd [14, 22] conducted extensive literature reviews describing the landscape of the SDP movement. According to the author, SDP initiatives were motivated by athlete activism, the reaction to the fall of apartheid and made openings possible by the end of the Cold War, the neoliberal emphasis on entrepreneurship and mass mobilizations for "Make Poverty History," as part of a major focus of UN political development and the SDP International Working Group [14, 22]. The current results of these global studies show that despite the potential benefits of sport, these positive social impacts do not automatically accumulate. Achieving positive impacts require professional and socially responsible interventions that are adapted to the social and cultural context, prioritize development objectives, and are carefully designed to be inclusive [10, 17, 23]. Nevertheless, some authors note the lack of scientific literature regarding the understanding of the specific mechanisms by which sport can foster development and peace among participants [9, 24, 25].

### 2.2 Exploratory field and case studies on the SDP

Second, some researchers have used several exploratory methodologies to conduct field case studies [26–28]. For example, Oxford [27] focused on the social inclusion of young Colombian women through football, a traditionally very male sport. The researcher conducted a 6-month ethnographic study in Colombian neighborhoods of the SDP organization to explore the social, cultural, and historical complexities surrounding the safe practice of girls' sports. Whitley et al. [28]

attempted to question key players in SDP about their experiences and expertise in the field. The study provided a better understanding of the limit, the lack of efficiency and equity in practices as well as a concrete impact that they felt was unclear. The study concludes with a list of recommendations to improve SDP field work, research partnerships, and evaluation collaborations in a more rigorous way. Finally, some authors such as Gadais et al. also aim to develop research methods adapted to the SDP field, which is often unstable, complex, or unsafe [26]. The authors intended to implement analyses and methods from a distance and on the field to better understand SDP organizations and their needs in order to better support them in their work.

### 2.3 Management and evaluation of SDP programs

Third, researchers are also interested in questions of program evaluation and management of SDP activities. On the one hand, SDP organizations are frequently approached by the funding agencies to conduct SDP program evaluation studies. This is a classic way of observing the impact of sport on social change [29–31]. The evaluation studies examined various aspects of the missions and paradigms of SDP projects [30, 32, 33]. A literature review conducted by Levermore [30] revealed three major limitations to SDP evaluation studies: (a) monitoring and evaluation are insufficient; (b) they are conducted with acclaimed programs; and (c) they tend to use a positivist logical framework (Levermore [30]). Levermore concluded his analysis by stressing the need for evaluations that can take into account the diversity of SDP projects, some of which have unclear objectives or missing justifications. Indeed, their objectives and strategies remain unclear and questionable in relation to fully implemented program evaluation protocols [30, 34]. Programs should be evaluated using solid methodological documentation on logical frameworks and critical participatory approaches to try to apply these approaches to specific case studies or to consider their use in the context of a particular sporting event [30]. On the other hand, some researchers aim to strengthen the managerial aspects of SDP projects to improve their functioning, management, or implementation mechanisms [34–37]. Often, the overall idea is to build connections between the theory generated by macrosociological studies and field case studies. Sport management specialists have begun to critically review and evaluate SDP initiatives, and they are now more strategically planned and pedagogically solid than before. For example, Schulenkorf [37] reviewed the main achievements of sport management research and classifies current research under four headings: (a) SDP programming and design; (b) sustainable management and capacity-building; (c) creation and optimization of impacts and outcomes; and (d) conceptual/theoretical advances. Finally, he suggested that future research could focus on the managerial concepts of leadership, entrepreneurship, and design thinking to maximize the potential of sport (management) to contribute to desired, innovative, and sustainable outcomes for community development.

### 2.4 Literature reviews on SDP

Fourth, three literature reviews have been conducted on SDP. Until 2016, there was little research to synthesize research on SDP. There was no mapping to know what projects existed and to have an overview of the situation at the global level. In 2017, the review conducted by Svensson and Woods [38] addressed this gap by providing a systematic overview of SDP organizations. While the precise locations of action of SDP organizations remain largely unknown, this review has focused these efforts and on the physical and sporting activities used in the programs. It provided an opportunity to review the practice of SDPs in order to provide an overview of the current state of the field: 955 entities involved in SDP practices were identified based on a systematic review of 3138 organizational entries in the SDP databases. The majority of organizations operate programs in Africa, but many are present in Europe, North America, Asia, and Latin America, with more than 80% of them having their headquarters in the same region. Education, livelihoods, and health emerged as the most common themes, while disability and gender were less represented. A total of 32 types of sports have been identified, one-third is only based on football (soccer). In relation to positive youth development (PYD) through sport, Jones et al. [39] conducted an analysis of how sport is a mechanism for achieving various development objectives. The review shows that this link between sport and development is not inherent and depends not only on a variety of programs and activities but also on contextual factors. The positive potential of sport does not develop automatically; it requires a professional and socially responsible intervention, adapted to the social and cultural context [17, 23, 30]. Finally, Schulenkorf et al. [8] conducted an integrated analysis of the literature on sport for development to provide a comprehensive and holistic picture of the sector. Despite the significant increase in published research in the field of sport for development, there has been no attempt to rigorously review and synthesize scientific contributions in this field so far. The paper shows an upward trend in scientific publications since 2000, with an emphasis on social and educational outcomes related to youth sport,

| Thematics | Descriptions |
|---|---|
| Sport and disability | Sport and disability focuses on research related to sport as a vehicle for the development, access, inclusion, and human rights of people with disabilities. This section encourages critical thinking and diversity of perspectives, welcoming research at the intersection of theory and practice. |
| Sport and education | Sport and education presents research and case studies related to interventions that use sport to advance education, youth development, and life skills. Rather than focusing on sport education, this section discusses the role of sport in achieving the academic and social outcomes of youth. |
| Sport and gender | The theme on sport and gender presents research and case studies related to interventions using sport to promote gender equality, challenge gender norms, and empower girls and women in disadvantaged environments. |
| Sport and health | Sport and health presents a wide range of outcomes associated with physical, mental, and social well-being. This is the effect of SDP programs on the risk factors for communicable and non-communicable diseases, including the direct effect of sports programs on physical activity. It also examines the role that sport can play in preventive education and health promotion interventions. |
| Sport and livelihoods | The theme on sport and livelihoods presents research and case studies on interventions using sport to improve the livelihoods of disadvantaged people, from programs focusing on vocational skills training to rehabilitation and social enterprise. |
| Sport and peace | Sport and peace focuses on projects that use sport as a vehicle for reconciliation and peace-building. The concept of peace is broadly defined to include connotations of personal, community, and social well-being, as well as the absence of conflict and tension between groups. In particular, this section examines the possibilities of creating peace between individuals and groups in socially, culturally, or ethnically divided societies. |
| Sport and social cohesion | The sport and social cohesion theme includes projects in the areas of community empowerment, social inclusion/integration, and diversity management. It focuses on social impact assessments and capacity-building initiatives that can lead to social cohesion, skills enhancement, and overall community development. |

**Table 1.**
*Research themes related to the SDP field.*

with football (soccer) being the most common activity. The vast majority of SDP research has been conducted at the community level, where qualitative approaches dominate (70% of conceptual and qualitative methods). The authors also noted an interesting paradox regarding the geographical contexts of the studies: a majority of the projects are carried out in Africa, Asia, and Latin America, but 74% of the study fields and 90% of the SDP authors are based in North America, Europe, and Australia.

### 2.5 SDP research themes

According to the Journal of Sport for Development, several research themes have been identified in relation to SDP (**Table 1**).

## 3. Illustrations of SDP research projects

### 3.1 Education, social inclusion, and environment: Bel Avenir (Madagascar)

Bel Avenir (BA) is a Malagasy NGO working in the southern region of Madagascar, through social projects, focusing on "education as a vehicle of development." BA carries out activities in various fields of education for young disadvantaged populations in Madagascar, particularly in Toliara and Fianarantsoa. The field of education includes: (a) formal education in two schools, (b) non-formal education including a school of sports and a music and arts center, among others, (c) awareness-raising projects, such as international inter-school exchanges, or publications of Malagasy stories. Thus, the organization offers a holistic approach to education for development and the SDP proposed by its school of sports, which is only one of its various services. The country is severely affected by extreme poverty, malnutrition, severe hygiene and health problems, child labor problems (mining or prostitution), corruption in society, and frequent political crises. In this sense, BA works in a complex context, most often difficult, unstable, and sometimes insecure, where reality could be ephemeral. BA is finally a member of the international network Agua de Coco, based in eight countries, and mobilized around children's rights.

Two research projects are currently running to support and strengthen BA's projects. The first study attempts to develop a methodology that uses the Actantial Model [40] and the Snakes and Ladders [7] to analyze and understand the NGO's situation from a distance [41]. By using the NGO's annual reports and comparing them to reality, the researchers are developing a methodology to verify whether a research can be successfully conducted in collaboration with the local organization. A second study, focusing on the needs of the NGO, aims to measure the effects of sports (school of sports) and artistic activities (arts and music center) [42] in order to understand their consequences on the psychological and social well-being of disadvantaged youth. This research also aims to strengthen monitoring and evaluation tools for young people and to set up a psychological unit to monitor young people in their development.

### 3.2 Training of life and sports coaches—Pour 3 points (Canada)

The non-profit organization Pour 3 points (P3P), established in Montreal, Canada, since 2013, uses sport as a tool to promote the development of youth in socio-economically disadvantaged neighborhoods. More specifically, P3P offers a 2-year life coaching training program for young Canadians who are interested in coaching and are willing to make a long-term commitment to the program and to disadvantaged communities. Their role is to learn how to support young people in their lives and to help them to avoid dropping out of primary or secondary school, and to support those who experience learning problems or have serious behavioral problems. By being well trained, coaches can help young people develop the skills they need to succeed in school and in their life. After parents, coaches are the most influential adults in the lives of young athletes according to P3P. This influence is felt not only in the teaching of the game but also in the teaching of life.

Coaches are recruited at the time of enrolment in the training program, based on the skills required to become life coaches while becoming sport coach in one of the organization's partner schools. Each year, the program recruits approximately 15 coaches who participate in a 4-day training retreat, five peer discussion circles, five formal training sessions, and three personal evaluations each year, all under the supervision of a development consultant.

Several research projects have been conducted with P3P. A first study conducted on the P3P training program [43], examined coaches' perceptions based on a humanist coaching workshop they received in their training. The results revealed that coaches perceive positive results in autonomy, communication, skills, motivation, and willingness to help their athletes' teammates. A second study was conducted to strengthen the organization's logic model to identify indicators for subsequent program evaluation. The results showed differences in the understanding of the program between key stakeholders. Recommendations from research allowed P3P administrators to reframe their theory of change [44]. This study was designed in collaboration with P3P administrators to help them improve their logic model and prepare their program evaluation. The idea for this research came directly from the P3P administrators and the researchers acted as facilitators.

## 4. Axis of tensions between practice and theory of SDP

Several tensions can be noted between the needs of practitioners and their realities on the field with the possibilities of SDP research. The aim is to identify them and then propose a plan for action and research (**Table 2**).

First, we can observe a first axis of tension around program evaluation. On the one hand, SDP organizations are often asked by their donors to conduct program evaluations. This allows them to justify the rationale for their projects and to demonstrate the effectiveness of their actions. However, if these evaluations are not well planned, negative results can be found that compromise projects. SDP organizations often call on researchers to help them conduct their program evaluation because it is a time-consuming process. On the other hand, researchers need precise and specific criteria to conduct a relevant program evaluation. Unfortunately, few projects are able to provide evaluators with these very important indicators to conduct a fair and meaningful evaluation.

Second, SDP projects are rarely perfect in their planning and implementation because they face limited resources and highly changing contexts. As well, it is necessary for administrators to make constant adjustments to improve the implementation and realization of their projects. While SDP projects are criticized by researchers in demonstrating several nonsense between the aims and actions of the project, it remains true that researchers would also benefit from offering a support and collaboration service to try to solve the field difficulties encountered by the actors.

Thirdly, another axis of tension can be detected on the managerial aspects of SDP projects. On the one hand, the administrations of organizations are

| SDP practice | Axis of tensions | SDP theory or research |
|---|---|---|
| **Practical needs of SDP** | | **Needs for research** |
| Evaluate effects or impacts of the SDP projects | *Program evaluation* | Need for indicators/criteria to conduct evaluation |
| Projects are imperfect and need be improve | *Critic/support* | Need to critic projects but also support actors and organizations |
| Reinforce administration team and management work | *Management* | Need to reinforce management elements of projects |
| What is the finality/use/form of SDP? | *Finality/use* | Need to identify the types of SDP and needs about thematics |
| What is the qualification/training of SDP personal/staff | *Training/workshop* | Need for research on training |
| Reality field could be unsecure, unstable, complex, dangerous | *Method/tools* | Need to improve quality of research and have adapted tools for investigation |

**Table 2.**
*Tensions between practice and theory on SDP.*

increasingly developing with their projects. As they do so, they must strengthen their structure and organization, which is often dependent on the financial and human resources at their disposal. On the other hand, researchers have started to conduct several studies to better understand the managerial aspects of SDP organizations, and it would be relevant if these studies could strengthen the organizational aspects of SDP projects which often do not have much support.

Fourthly and for the time being, few differences have been made in SDP projects between those aimed at elite sport, competition, physical education, physical activity for leisure, or another theme such as health education through SDP. In our opinion, there is a very important tension about the purpose, use, and form that the SDP can represent and be truly in field projects. While several texts have been written to attempt to highlight these elements, few studies have attempted to go further in understanding what the SDP really is. This research seems essential to us to make the difference between the various forms of SDP and their multiple uses. This will eventually make it possible to identify new themes to investigate around the SDP.

Fifth, there are currently many questions around who are the people who work with the populations in SDP, what are their training or qualifications? While the research strongly recommends the use of sport supervised by qualified and trained personnel, few studies have focused on the profiles and the training of those people who work in the field every day. On this axis of tension, research must propose areas of response to strengthen field actions. And on this point, it is therefore necessary for researchers to go down to the field to see and understand the reality of the projects.

Finally, SDP fields are often dangerous and unsafe as they are located in humanitarian crisis or international development situations. These situations can change in a few minutes and working in this environment is therefore extremely unstable. They also face very complex realities in which it is necessary to take into account as many elements as possible in order to operate. Faced with the reality of this type of terrain, researchers must adapt their work. In particular, research methods and tools must evolve to adapt to a changing reality and to conditions that are sometimes very inappropriate for conducting a traditional research project. These adaptations are necessary to improve the quality of research in SDP's fields.

## 5. Future research perspectives on the SDP

SDP research now offers a better understanding of the movement and allows practitioners to better orient themselves in their use of sport for development. However, the research also raised a set of concrete issues for field projects and some questions remain unanswered at this time. Following the results of the latest studies, six main areas of work should be considered to guide further research on SDP.

1. Provide a space for reflection (criticize vs. support): current research is often critical of SDP projects and too rarely supports or improves the action of actors in the field. However, it seems important to strengthen the work of the actors while continuing to question their actions and achievements. In this sense, the researcher must offer a space for joint reflection with the actors in the field;

2. Use a collaborative or partnership approach to conduct research (be a facilitator): one of the roles of research is to help solve practitioners' problems. Specifically in the domain of SDP, field actors express difficulties and needs that must be listened in order to co-construct research projects. In this sense, the researcher should act as a facilitator to support the projects and the work of the actors while continuing to criticize them in his/her support;

3. Starting from the concrete angle of the field: to be able to fully understand the nuances of the context and/or the environment of the SDP actors, researchers are invited to be as close as possible to reality, and to step into the field as possible. This element is essential to build a relationship of trust with the actors to help them by understanding their background and endings as much as possible;

4. Seek interdisciplinary research: SDP themes are complex and often overlap with scientific knowledge from several research fields (e.g., sociology, psychology, and education). Researchers from several scientific disciplines must be open and work together as much as possible, in order to have the most precise and complex understanding of the phenomena that are difficult to capture from a single angle. Research must provide a better understanding of the multiple issues and the complexity of the issues, problems, and realities;

5. Propose better quality of research: it also seems relevant to us to question how to carry out better quality research on ephemeral or unstable fields, when access is considered complex and dangerous. This requires, among other things, the development of methods able to adapt and respond to the requirements of the domain as well as to the various fields of investigation;

6. Clarify the uses of SDP: finally, it seems essential to us to question the type of sport for development and peace that is used in the various contexts of SDP. More specifically, is it competitive sport, physical education, physical activity, health education, or any other form? On this subject, Hills et al. [45] had opened up interesting avenues for reflection by mentioning sport + and + sport [46], sport for social inclusion [24], sport as a universal language [1, 24], sport as a diversion [47], as a replacement or alternative [48], as a hook [49, 50] or for life skills [51, 52], among others.

## 6. Conclusion

This chapter aimed to present the field of SDP, its origins, its evolution, the research that has been carried out so far, as well as illustrations to give the reader a better idea of what "Sport for Development and Peace" is. However, answering the question "what is the SDP?" is not easy given that this field is vast, complex, and constantly changing in practice.

In conclusion, three main elements can be remembered: (1) a large number of projects and programs have been developed since the 2000s, mainly in Africa, Latin America, and Asia, with football being the main sport [8, 38]. Other various forms of physical activity and sports (e.g., physical education, competitive sport, and leisure activities) have also been used in order to achieve development or peace and related topics; (2) research on SDP has intensified since 2010 [8]; and it can be grouped into four main categories of studies: macrosociological, exploratory field studies, managerial and program evaluation, and literature reviews; (3) several challenges and tensions remain to be resolved in order to accomplish quality research that will truly help and support actors from the field who use SDP.

We can finally return to the proposals of Baron de Coubertin and Mandela, who were very visionary in using sport as a vehicle for development and as a means of establishing peace. Because today, many organizations such as the United Nations prefers to rely on the universal potential of sport or other non-formal recreation to resolve conflicts and educate future generations, rather than traditional institutions such as schools or governments.

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## Conflict of interest

The author declares no conflict of interest.

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Section 3

# Advances in Wearable Technologies

Chapter 4

# Challenges and Future of Wearable Technology in Human Motor-Skill Learning and Optimization

*Gongbing Shan*


## Abstract

Learning how to move is a challenging task. Even the most basic motor skill of walking requires years to develop and can quickly deteriorate due to aging and sedentary lifestyles. More specialized skills such as ballet and acrobatic kicks in soccer require "talent" and years of extensive practice to fully master. These practices can easily cause injuries if conducted improperly. 3D motion capture technologies are currently the best way to acquire human motor skill in biomechanical feedback training. Owing to their tremendous promise for a plethora of applications, wearable technologies have garnered great interest in biofeedback training. Using wearable technology, some physical activity parameters can be tracked in real time and a noninvasive way to indicate the physical progress of a trainee. Yet, the application of biomechanical wearables in human motor-skill learning, training, and optimization is still in its infant phase due to the absence of a reliable method. This chapter elaborates challenges faced by developing wearable biomechanical feedback devices and forecasts potential breakthroughs in this area. The overarching goal is to foster interdisciplinary studies on wearable technology to improve how we move.


**Keywords:** biomechanics, 3D motion capture technology, body model, real time, feedback training, AI, IMUs

## 1. Introduction

For decades, it has been known that the large and widespread anthropometrical diversity limits the effectiveness of a universal approach in human motor-skill learning and training; instead, an individualized biofeedback approach would significantly improve the learning process [1–4]. Recently, wearable sensors (wearables) have garnered great interest in biofeedback training, owing to their tremendous promise for a plethora of applications [5–8]. It seems that individualized biofeedback training has the potential to become an immediate reality in the motor learning realm. However, the absence of a reliable method of applying wearables in biomechanical feedback training has greatly hindered their application in human motor-skill learning and optimization [4].

Although wearables in sports are only a few years old, there has already been a consensus that wearable technology is leading a revolution in physical training [5, 8]. Various sensors are now fitted into sport equipment, limbs, wristbands, and/or clothes to collect crucial data in real time, sending it directly to trainers, allowing them to implement an individualized training plan for increasing athletic competence. Nevertheless, the use of real-time biomechanical feedback in training looks currently not so optimistic. A recent review paper (2019) divulges that the biomechanical development is still in its infancy [4]. The paper reveals that while there are over 5500 published biofeedback articles in Web of Science, there are very few on real-time biomechanical feedback learning or training. Compared to the booming application of wearables in fitness as well as in health industry, the biomechanical investigations seem disproportionately low. The scarcity of biomechanical studies may due to two facts: (1) a general biomechanical body model that is suitable for wearable application in feedback learning and training is missing, and (2) a reliable method for linking biomechanical quantification and human motor learning in real time is still not available [4].

Clearly, the current success of wearables in sports is not yet linked to the human motor-skill learning. The overwhelming use of wearables in sports is mainly in the area of monitoring physical condition. For example, sports injuries are often caused by fatigue, overtraining, or dehydration [9, 10]. Wearables are now able to collect data related to the risk conditions from athletes' physical conditions, muscle activities, and sweat [5–7]. The real-time biofeedback can help coaches to quickly alternate their training or competition strategies in order to decrease injury risk in training and competition [5, 6, 9]. One should note that the locomotion (e.g., distance, speed), physiological (e.g., heart rate, blood pressure), neurological (e.g., muscle activities), and biochemical feedback (e.g., electrolytes, metabolites) are only useful in analyzing the general physical condition of an athlete; however, they do not provide information related to the limbs' control of human motor skills, and as such, the biomechanical feedback for motor control is still missing.

## 2. The uniqueness and challenges of developing biomechanical feedback

Why is the development of biomechanical feedback understudied? This is because of the uniqueness of biomechanical feedback. Feedbacks obtained from locomotion, physiological, biochemical, and neurological measurements deliver information of one's general changes in speed/location, physiological and physical response, and muscle tension. The common point of these feedbacks is that they can be conserved across human motor skills, i.e., across different movement forms. Therefore, one can universally apply the feedback devices monitoring these parameters of all activities [4, 11]. On the contrary, biomechanical feedback mainly provides information related to the limb control of motor skills, which often differ from one skill to the other. To complicate matters further, skill optimization has to be adjusted depending on one's anthropometry [4, 12–14]. In short, biomechanical feedback must be tailored to an individual activity being examined [15–18].

Ergo, in order to develop a universal biomechanical feedback device, one has first to obtain a thorough understanding of a variety of motor skills in order to determine the general key parameters for monitoring [1, 4]. Further, biofeedback devices (e.g., wearables) must not interfere with the motor skill being executed. This technical limitation alone has proven to be a major hindrance to the development of biomechanical feedback in motor learning and training. Finally, a vital step in device development is to search ways/body models, which should consider the anthropometry-induced motor-control variations.

In short, there are three indispensable linchpin pieces in the development process: (1) expert knowledge obtained from extensive motion analyses of diverse human motor skills, (2) sensibleness of wearables' application in training environment, and (3) a general method for wearable-based data analysis and interpretation.

Summarized above, there are several challenges that must be overcome during the development of the universal real-time biomechanical feedback. The obvious are:

- Creating a new generalizable body model that can quantify various human motor skills
- Minimizing wearable interference with the motor skill being executed
- Developing wearable-based data analysis and interpretation method
- Adding the anthropometrical variation into motor-control identification

## 3. Biomechanical steps in developing wearables for feedback training

Effective human motor-skill learning can be supported by useful and timely biomechanical feedback to learners, helping them to target at their performance defects. Previous studies have shown that regular, objective, and consistent performance monitoring and assessment through quantitative analysis of biomechanical variables can reinforce the biomechanical feedback training in practice [17, 19]. Therefore, how to increase the spatial and temporal accuracy when performing a quantification of a motor skill (i.e., the limbs coordination) would play a crucial role in developing wearables for biomechanical feedback training [20]. Considering the uniqueness of biomechanical feedback illustrated in the previous sections, the following steps have to be undergone in developing wearables for feedback training:

- Choose a motor skill.
- Perform motion analysis of the skill quantitatively.
- Identify dominate parameters for feedback training.
- Verify the effectiveness of the selected feedback(s) in practice.
- Develop a feedback device for monitoring of the critical/vital parameter(s) (e.g., coordination among certain segments or joints) for the given motor skill.

One should note that wearables developed through the current approach can only be applied to one specific motor skill. A delimitation of application in learning/training other motor skills is impossible.

Having seen the success of physiological, neurological, and biochemical wearables in practice, it would be a practitioner's desire that the biomechanical one could also be universally applied to all motor skills for their learning and training in sports and arts. One should note that a general application means that a general methodology should exist for motor-control data collection and interpretation, i.e., a wearable system should be able to track a variety of human motor skills and to identify the motor-control patterns existing in these motor skills. Unfortunately, we are currently still far away from the goal. All existing studies are specific or isolated ones. So far, only a few studies explored the real-time biomechanical feedback application in practice [21–23].

## 4. A novel route in developing wearables for human motor-skill learning and biomechanical feedback training

Currently, the most reliable methodology for quantifying complicated human motor skills is the full-body biomechanical modeling based on 3D motion capture [24–27]. The biomechanical body model consists of 15 segments. The 15 segments are the head, upper trunk, lower trunk, upper arms, lower arms, hands, thighs, shanks, and feet. For establishing the model, about 40 body-surface markers are needed to supply 3D coordinate inputs for mechanically determining joint kinematics in order to reveal the motor-control/limbs' coordination. The model is widely applied in the current 3D motion capture technologies for demystifying and optimizing complex motor skills in sports and arts performance [4, 15, 17, 28–36]. This video-based technology uses multi-cameras to track ~40 reflective markers (their weights are negligible) attached on the body surface. Technically, the tracking can be equivalently done by using 40 wearable IMUs, a sensing technology that measures linear and angular motion with a triad of gyroscopes and triad of accelerometers [21, 37–40]. As such, motion analysis could switch from labs (multi-camera environment) to the field (wearables) [4], i.e., quantification of limbs' coordination would be no more restricted to labs and become an effortless daily routine for researchers and practitioners. Practically, it is not so easy.

It is wise to induce the success of the current biomechanical body model into wearable applications. Nevertheless, it is unrealistic and impractical to use ~40 IMUs for rebuilding the body and its movement. Markers used in motion capture are small (9 mm in diameter) and almost weightless [41–43], whereas the volume and weight of current IMUs are still significantly larger. The ~40 IMUs can cause unknown experimental artifacts. Obviously, we have to search a new route. Based on the current development [4, 20, 21, 44], a novel approach for a potentially successful transition to wearable applications will be introduced here.

The innovative approach will be built on previous studies on anthropometry [12, 13, 45], 3D motion analysis [25, 46–49], sensing technology [21, 37–40, 50], and artificial intelligence (AI) [44, 50–54]. This multidisciplinary approach provides a new route to develop a wearable-based method for data analysis and interpretation (motor-control depiction) as well as to distill and package new findings from various areas in realizing the real-time biomechanical feedback training in practice.

### 4.1 A two-chain model as a general full-body biomechanical model for realizing wearable application in human motor-skill training

In 3D motion capture, the rebuilding of an individual 15-segment model is achieved by tracking selected body-surface markers in 3D space. Alternatively, an equivalent model can be built via anthropometrical approach. Previous studies show that, using variables such as body weight (BW), body height (BH), gender, and race, one can statistically determine segmental masses and lengths to build an individual body model [12, 45]. The difference of the two approaches is that the former is "born-to-move" (video-based) and the latter has to "learn-to-move" (wearable-based). Currently, the most challenging for wearable application in sports and arts performances is practicality. Wearables attached to human body will create certain constraints for human movement and alternate the movement control in a way that may not reach the training goal. Therefore, the less wearables applied, the more practical the feedback system is. Aiming at the development of practicality, future researches/developments should focus on innovative designs of the body model that will minimize the number of wearables required yet still supply equivalent, if not better, accuracy of the current 15-segment biomechanical model. Such a novel body model is introduced below for potential breakthroughs in the future.

Based on numerous previous 3D motion studies [15, 28–31, 37, 55–63], multitudinous complicated human movements from both sports activities and arts performances can be generally represented by using a model system with two mechanical chains: upper-body chain and lower-body chain (**Figure 1**). The upper-body chains consist of a base (i.e., upper trunk and head) and two sub-chains (i.e., arms) that are linked to the base. The lower-body chain has an equivalent structure, the base is the lower trunk, and the two sub-chains are the legs. With this novel design, human motor skills could be tracked by using much fewer IMUs. Theoretically, three IMUs on each chain (one on the base, one on each distal end of the chain) would likely track the movement of a chain (**Figure 1a**), i.e., six IMUs would be able to determine the segments'/joints' motion and coordination as well as the orientation relationship between the two bases of the two chains. As such, researchers and practitioners could quasi-naturally track human motor skills (i.e., six wearables would minimally encumber human motor control) in learning and training. This would help the development of the real-time biomechanical feedback training. Only the six IMUs' inputs are not

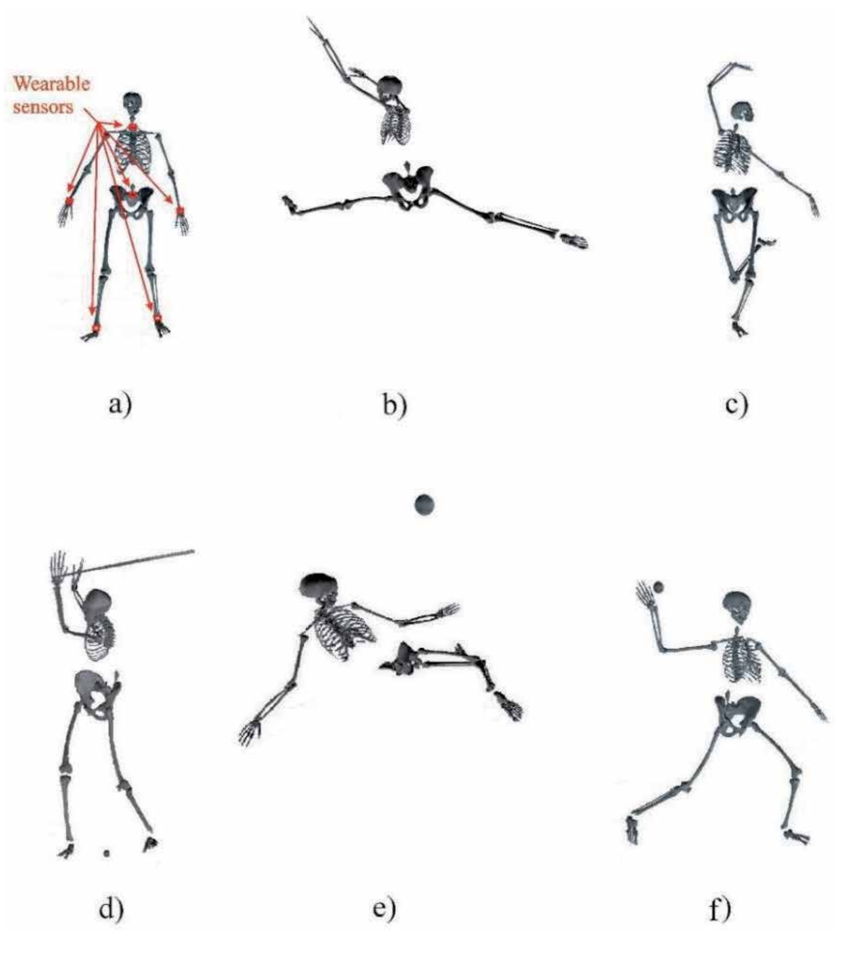


**Figure 1.**
*The two-chain model of human motor skills. (a) the possible locations of the six wearables for human motor-skills' tracking; (b) grand jeté in ballet; (c) an Indian dance skill; (d) golf swing; (e) jumping side volley (an acrobatic kick) in soccer; and (f) baseball pitch. Note: All the three-dimensional motion data were generated in Shan's biomechanics lab.*

sufficient to apply the class mechanics to quantitatively determine the model system. Currently, AI could alleviate this challenge due to its "learning" ability [44, 64–66].

### 4.2 AI for motor-control quantification

Since the inputs of the limited IMUs cannot mechanically determine the two-chain model, AI technologies are the alternative ways for the two-chain model quantification. Studies have shown that AI techniques have become a powerful tool for helping to solve many challenging problems in human motor-skill evaluations and analyses [44, 52, 53, 67].

The basic idea of AI prediction is to find a way to learn general features of existing data in order to make sense of new data [64, 65]. This description highlights the central role of data for establishing implicit knowledge. The amount of data must be sufficiently large to provide many training examples from which a large set of parameters can be extracted. In the past decades, AI techniques have experienced a resurgence following concurrent advances in computer power, large amounts of data (big data), and theoretical understanding.

Among the AI technologies, deep learning is considered as a powerful tool that percolates through to all application areas of AI, such as image identification, speech recognition, natural language processing, and, indeed, biofeedback support [68–70]. The success of deep learning networks encourages their implementation in further applications for the enhancement of human physical activities [52, 54, 67]. Recently, *Nature Neuroscience* has published the latest developments in the area of markerless, video-based motion tracking, indicating that the power of deep learning will enable motion tracking to human-like accuracy [53]. This study confirms that motion capture/quantification of limbs' coordination will move from an expensive and difficult task restricted to the laboratory to an effortless daily routine for researchers and practitioners.

From motor learning point of view, wearables would have much higher potential than video shooting in the future practice. This is not only because of the fast advance in miniature of wearables but also due to three inherited drawbacks of video-shooting approach, i.e., (1) the limited capture space, (2) the complexity of capture systems (from setup, calibration, to operation), and (3) the time-consuming nature of data processing (high cost of data processing). Reliable biomechanical feedback should be obtained from accurate quantification of human movement in field, with some requiring large space. Even with a multi-camera setting, unexpected environmental factors (e.g., interactions among athletes) will create a data gap. Further, it is true that we are already sitting on massive movement data (e.g., YouTube, Flickr) for training of deep learning models; but the video datasets are uncalibrated and have very little information on the hardware and conditions used to capture particular videos, which can bias the deep learning recognition algorithms [71]. Currently, the availability of reliable motion capture data for developing deep learning models is significantly limited.

In summary, the combination of the two-chain full-body model with six wearable IMUs and the deep learning prediction based on IMUs' data shows great potential in developing real-time biomechanical feedback training for an efficient human motor-skill learning and optimization. The missing piece for testing the potential is reliable massive training data.

### 4.3 The key for raising the reliability of wearables: creating a diversification of 3D training big data

Two factors revealed by previous studies strongly influence deep learning performance [65, 66, 72–74]. One is the massive data, and the other one is the diversity of the massive data. A systematical review article has examined 53 studies published before 2018. The scope of the review is the deep learning applications of the physiological data or signals in healthcare. The article has revealed that both the amount of data and the diversity of data would influence the prediction's reliability [65]. This result would signify that deep learning algorithms would perform well with large and diverse datasets.

Judging from the current knowledge, a massive and diverse 3D motion capture big data, collected from sports and arts activities, is indispensable for developing the reliable biomechanical wearables. It is well known that sports and arts skills exhibit the most diverse and complicated motor controls among all human physical activities. If such big data are available for training deep learning models, the reliability of the trained model will be raised due to the depth and specialization from training the deep learning algorithms [65, 66, 72–74]. Therefore, at present, the vital step for developing real-time biomechanical feedback tool is to apply the two-chain model in simultaneous collections of a large amount of motion data, i.e., synchronized measurements using both 3D motion capture with ~40 markers and 6 wearable IMUs [35]. The synchronized data collection should cover large variety of sports skills and arts performances. As such, the 3D motion capture data can be served as a "supervisor" for training deep learning model to map IMU data to joints' kinematic data. Such a deep learning model could be reliably and universally applied in motor learning and the training of sports and arts skills.

Retrospectively, the current knowledge of anthropometry, biomechanical modeling, and deep learning and the technology for miniaturizing IMUs supply an almost perfect environment for the development of the real-time biomechanical feedback tool in human motor-skill learning and training, especially in learning complicated skills in sports and arts. The missing piece is the massive and diverse motor-skill big data for deep learning.

## 5. Conclusion

This chapter highlights the challenges and future of wearable technology in human motor-skill learning and optimization. It introduces a novel two-chain biomechanical body model with six IMUs that are powered with deep learning technology. The framework can serve as a basis for developing real-time biomechanical feedback training in practice. In order to create a universal biomechanical feedback device for learning and training of any human motor skill, the massive and diverse big data of multifarious human motor skills have to be created first. One realistic way for obtaining the big data is through a synchronized measurement from 3D motion capture and IMUs. Evidently, gaining high-quality, full-body motion data across sports and arts performances would currently be the vital step for the real-time biomechanical feedback development.

The realization of the methodological breakthrough will allow us to transform the human motor learning paradigm from a largely subjective art into a precise scientific method. The potentials would be to (1) take scientific monitoring of motor skills from a lab-based environment into the field; (2) simplify a scientific movement quantification, transitioning from using a complicated motion capture system to easily applied wearables; and (3) transfer the vital biomechanical feedback in real time to prevent the worst/movement errors from happening while finding individual compensation/optimization. This methodology is the culmination of research programs in biomechanics, anthropometry, computer sciences, pedagogy, and equipment development. It aims to build innovative technologies for generating new knowledge as well as practical and definitive scientific methods for empowering motor learning. Fulfillment and application of the new wearable-based method in the future will benefit diverse human physical activities, including, but not limited to, motor-skill acquisition in sports, arts performances, health/fitness, and recreational activities.

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Chapter 5

# Smart Wearables for Tennis Game Performance Analysis

*Marko Kos and Iztok Kramberger*

## Abstract

For monitoring the progress of athletes in various sports and disciplines, several different approaches are nowadays available. Recently, miniature wearables have gained popularity for this task due to being lightweight and typically cheaper than other approaches. They can be positioned on the athlete's body, or in some cases, the devices are incorporated into sports requisites, like tennis racquet handles, balls, baseball bats, gloves, etc. Their purpose is to monitor the performance of an athlete by gathering essential information during match or training. In this chapter, the focus will be on the different possibilities of tennis game monitoring analysis. A miniature wearable device, which is worn on a player's wrist during the activity, is going to be presented and described. The smart wearable device monitors athletes' arm movements with sampling the output of the 6 DOF IMU. Parallel to that, it also gathers biometric information like pulse rate and skin temperature. All the collected information is stored locally on the device during the sports activity. Later, it can be downloaded to a PC and transferred to a cloud-based service, where visualization of the recorded data and more detailed game/training statistics can be performed.

**Keywords:** smart wearables, inertial sensing, tennis, biometric data acquisition, movement detection, sports tracking

## 1. Introduction

The use of electronic devices in our daily lives is growing constantly; therefore, it is no real surprise that electronic wearable devices are nowadays a big hit. Smart jewelry, smartwatches, fitness trackers, etc. are getting smaller and more capable due to the improvement of sensors, batteries, and microprocessors. Wearable technology has been in use a long time by the military and medical professionals, but the market for smart wearables for private consumers has only recently started to grow. The market for smart wearables is on a rise. In the smart wearables segment, smartwatches are the most valuable, accounting for 60% of market value, followed by fitness and health trackers, smart jewelry and smart fashion [1]. Many solutions and products in the smart wearables industry are developed by young companies and start-ups, which are competing against large international companies for their piece of the smart wearables market. Smart wearables have found their use in several sports applications, for example, for athlete's performance monitoring in sports like swimming, boxing, golf, soccer, tennis, basketball, baseball, etc. Measuring performance, tracking motion, and monitoring biometric data usually includes many metrics (acceleration, temperature, angular speed, pulse rate, etc.). Sensor miniaturization, small power consumption, and low power wireless communication technologies have enabled researchers and engineers to design miniature, lightweight wearable embedded devices that can be placed in a shoe, worn on a wrist, or are incorporated into the sports equipment (like racket handle). Such devices are also popular for fitness tracking, potential injury prevention, or health monitoring. For example, a miniature wearable device is used for linear and angular head accelerations monitoring in football for detecting the potentially dangerous head impacts. The device is mounted in the player's helmet, and it records the amplitude and frequency of the player's head impacts [2, 3]. A miniature swing tracker was presented in Lightman [2], which can be used for monitoring different swing metrics for baseball and softball. It can monitor information about power, speed, and hitting zone of the swings.

With the popularity of the smartwatches and other smart wearable devices with integrated sensors, there is less need for the application-specific hardware development for specific tasks. Smartwatches generally have built-in MEMS (microelectromechanical systems) accelerometers and gyroscopes, pulse-rate (PR) sensors, etc. Therefore, only software applications for these devices need to be developed. One of these applications was developed for aiding an athlete with baseball pitching action and tennis serve action [4]. The personal sport skill improvement support application is running on Sony's SmartWatch SWR50. Comparative research was made by using the proposed sport skill improvement support and very encouraging results were achieved. Similar to the abovementioned system, authors in Viana et al. [5] proposed an application called GymApp, which is a real-time physical activity trainer. It runs on Android-supported smartwatches, and it supervises physical activities, for example, in fitness. It has two modes of operation: training mode and practice mode. In training mode, an athlete is advised to perform an exercise with lighter weight and with the supervision of a fitness instructor, to guarantee the correctness of the performed exercise. The application then gathers sensory data and builds a model for the performed exercise (e.g., biceps curl). In the practice mode, the recorded sensory data are compared with the previously acquired data and similarity distance is calculated. By evaluation of the similarity distance result, the application estimates how many repetitions of the exercise were performed correctly.

Several systems were developed also for boxing. They provide punch analysis and type statistics. Usually, a small embedded device is fitted into the boxing glove where different punchers are detected and distinguished based on accelerometer data [6]. Small embedded devices for tracking, analysis, and statistics were proposed also for basketball and soccer. A shot/pass classification system for activity analysis during a match was presented by Schuldhaus et al. [7]. The proposed system uses a miniature IMU for movement tracking. They developed a low-cost embedded system for a shot and pass statistics, which is especially suitable for use during training and competition. A system for counting shots made or missed was proposed for basketball. It uses double sensor-node principle, where the first sensor is attached on the player's wrist. The wrist sensor records and detects each shot attempt. The second sensor is located on a basket's net where it monitors the statistics of made and missed shots [2].

Although smart wearable devices are nowadays being very popular and are in use by amateur and professional athletes a daily basis, the majority of the sports leagues still do no approve smart wearable devices for in-game use. A safety factor is also an issue, and on the other hand, some athletes expressed their concern about privacy matters. The International Tennis Federation (ITF) was one of the first Sports Federations, which allowed the use of smart wearables. From January 1, 2014, tennis players are allowed to wear sensors during the matches, and they can freely check important information during set breaks [8]. One of the sports associations, that also approved the use of wearable biometric devices during the game, is Major League Baseball. In their case, players are allowed to wear a special biometric baseball sleeve, which can monitor strain on pitching arm, and a body harness, which can detect and track players' movements on the pitch [9].

The way in which the smart wearable device is designed and the way it performs, it is especially suitable for swing-based sports, like golf or tennis. Although various systems and devices are commercially available, there is not much publicly available information on how they are constructed. In the area of tennis stroke recognition based on a visual approach, much has been previously published [10, 11]. For major tennis competitions, like Grand Slams and others, the ITF approved the use of a sophisticated video system, called Hawk-Eye. The system uses several calibrated high-speed video cameras, which are stationed around the court [12]. The drawback is that it is very expensive, and it takes a lot of time to set up and calibrate. Other systems and principles are more appropriate for everyday use, such as using a device with IMU.

Similar systems, that are IMU based, are also available for other sports. Swing motion detection using an inertial-sensor-based portable instrument was proposed for golf [13]. The miniature device is mounted on a golf club to measure swing motion signals. Procedures for signal collection, signal pre-processing, and swing motion segmentation has been developed. Results show that the instrument can be a promising tool for serving as a training assistant tool for golfers. Authors in Jensen [14] presented a device for golf put analysis. The device uses a removable sensor, and it is built solely from off-the-shelf components. It supports automatic putt detection and parameter calculation in real time.

Four different principles, that are used for smart embedded solutions integration, exist for tennis: (a) a device is placed in a tennis racket handle [15]; (b) a device is mounted on the racket strings (like a string vibration dampener); (c) a device is attached on the racket grip (at the bottom end); and (d) a device is worn on tennis player's wrist. The option with a sensor being integrated into the racket handle is also the most expensive because one must buy a special tennis racquet. Well-known tennis equipment manufacturer Babolat produces such rackets. The electronic device installed in the racket's handle monitors players' motion and swings. It connects with smart devices via Bluetooth for communication with a mobile app. The data from the device are then synchronized with the mobile app via Bluetooth. The mobile app is used for visualization of most common game statistics and some details regarding basic tennis strokes. The embedded electronics in the racquet handle uses IMU and piezoelectric sensors to detect the strokes [2].

Büthe et al. in their work proposed a system for complete movement monitoring during a tennis match [16]. The system uses three IMU devices. They are attached to each foot and to the tennis racquet. The proposed solution supports the detection and classification of leg and arm movements. Gesture recognition for the active arm based on the longest common subsequence (LCSS) is also supported. The proposed system was tested with four different players, where the results showed highly user-dependent performance. The proposed method achieved 87% recall and 89% precision for stroke detection. Regarding step recognition, the proposed algorithm was able to detect 76% of the steps. The step classification accuracy was 95%.

Tennis serve analysis system with a wearable motion sensor was presented by Sharma et al. [17]. The player gets the feedback from the analytics engine for enhancing their serve performance while preventing potential injuries. Samsung smartwatch Gear S2 was used for sensing and hand movement tracking. It has six-axis IMU with a measuring range of ±8 g m/s$^2$ (accelerometer) and ± 2296°/s (gyroscope). The IMU was sampled with the frequency of 100 Hz. For tests and experiments, a database of 1844 serves from various players (professionals, amateurs, and children) was used. The videos and sensor data are synced timewise and further prepared for correctness validation of the developed algorithms. The tennis serve is partitioned into key phases (start, trophy pose, cocking position, impact, and finish), and later features like consistency, pronation, backswing type, and follow-through are derived from inertial sensor data. Quaternion distance is used for serve consistency evaluation between medoid (general swing model) and the individual stroke.

Authors in Connaghan [18] presented a multi-sensor tennis stroke classification. For tennis stroke recognition, they used a single IMU attached to a player's forearm. Experiments were made during a competitive match. A two-level classification method was used for tennis stroke classification. Firstly, non-stroke events are filtered and after that stroke candidates are classified into three most common tennis strokes: serve, backhand, and forehand. Experiments showed that sensor fusion approach yielded the best tennis stroke classification. Ninety percent accuracy was achieved.

Tennis ball speed estimation using a motion sensor was presented in [19]. TennisEye, as the authors call it, is a system with racket-mounted motion sensor. It senses linear and angular accelerations and sends them to the smartphone device via BLE (Bluetooth low energy) wireless connection. Tennis strokes are detected using a threshold-based method and divided into three categories: serve, groundstroke, and volley. Authors compared the performance of their system against Zepp [20], which is a similar device mounted on the racket handle. To estimate the serve ball speed, a regression model is proposed. For groundstroke or volley, two models are proposed: a regression model and a physical model. For estimating the ball speed for advanced players, authors use the physical model and regression model for beginners. Using the leave-one-out cross-validation test, the evaluation results show that TennisEye performs better than its competitor.

Tennis stroke detection and classification is motion detection and classification problem, which can be observed also as a hand-gesture classification case [21]. For this type of tasks, some popular methods are widely used, like hidden Marko models (HMM) or dynamic time warping (DTW) and similar (like QDTW) [22].

## 2. Movement and biometric data acquisition

In the following section, we will present a miniature wearable device for tracking tennis swings and strokes. The presented system supports athlete's arm movement tracking, where individual hand gestures can be detected (like strokes etc.), and biometric data monitoring like skin temperature and pulse rate (PR) or even pulse rate variability (PRV). This additional information can be helpful for estimating the physical and mental state of an athlete. The system can work in continuous sampling or in gesture recognition mode, depending on the firmware. The system is presented in **Figure 1**. The system for movement and biometric data acquisition is composed of two parts: (1) a smart wearable module for tracking movement and gathering biometric data and (2) cloud service for detailed data analysis and visualization. A PC or smartphone device with a special application is used to download the gathered information from the wearable device to the cloud via the Internet. The main parts of the system will be presented in more detail further below.

### 2.1 Hardware design of the smart wearable device

The main objective of the hardware design of the proposed wearable device was to develop a lightweight device for tracking a player's movement and sensing its biometric information. The device should be attached to the player's wrist, and it

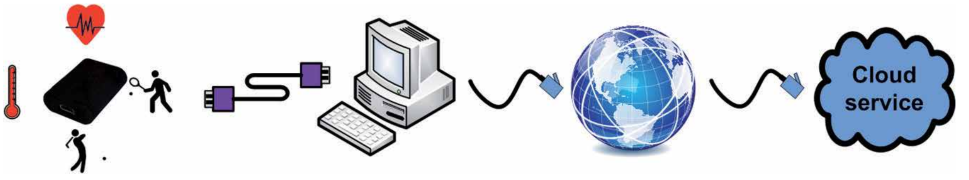


**Figure 1.**
*Architecture of the movement and biometric data acquisition system. The gathered information is uploaded to a cloud service via the Internet.*

should not influence the player's abilities for sports performance. One of the better places for device's attachment on the hand is right above the wrist (ulnar head), where there is enough soft tissue between the bones (the ulna and the radius) to successfully detect and measure pulse rate using photoplethysmography (PPG) method. The spot of attachment of the smart wearable device on the sportsman's forearm and the orientation of the individual IMU's axes are visible in **Figure 2**. The axes of the gyroscope are pointing in such a way that the angular rate is positive in a counter-clockwise direction if the accelerometer arrow is facing toward you.

We developed the wearable device with the wish for independent operation and the possibility to detect and classify basic strokes in real time. For this task to be successful, the sampling rate of the IMU unit must be high enough. We estimated that a sample rate of 1000 sps should suffice, after studying literature on racket body and racket strings vibration [23]. To be able to handle such amount of data, the wearable device must have large memory space to be able to store movement and biometric information reading for at least an average tennis match. An average tennis match lasts for about 2 h, and we rarely can see a match longer than 5 h. The record for the longest tennis match is held by Isner and Mahut. Their match lasted for 11 h and 5 min. It happened in Wimbledon in 2010. The percentage of total playing time for a tennis match is around 23–30% on clay and 10–15% on fast courts [24]. For maximum battery life, we implemented wired USB connection (instead of wireless, e.g., Bluetooth) for movement and biometric readings. The USB connection is also faster, and the USB connector can at the same time be used for battery charging. Detailed composition with the presentation of individual subsystems of the smart wearable device is presented in **Figure 3**.

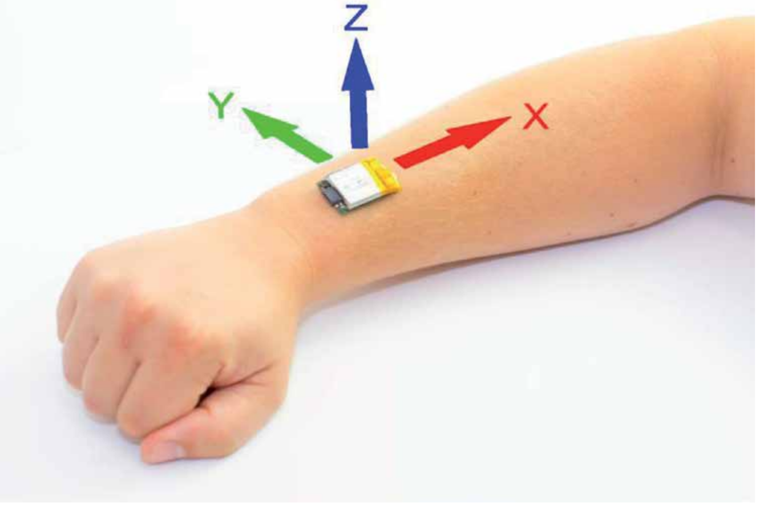


**Figure 2.**
*Smart wearable device position and IMU orientation. The device is attached above the wrist.*

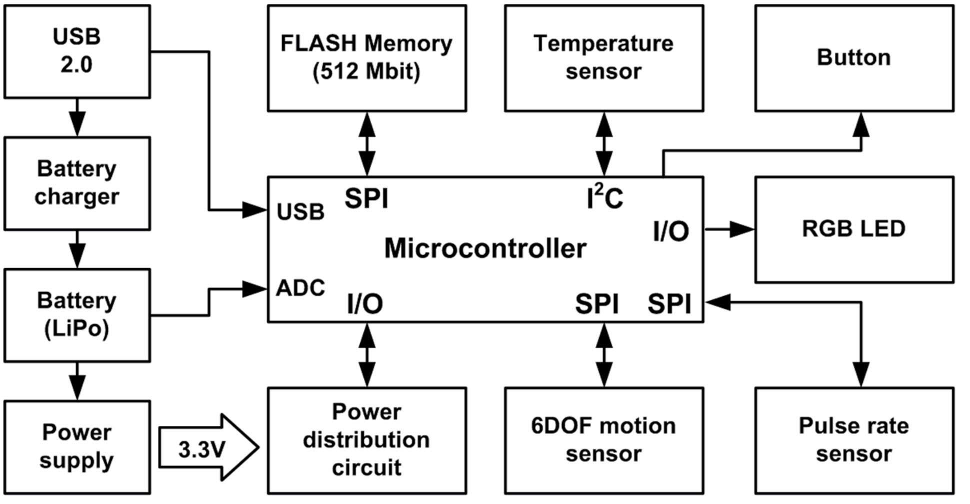


**Figure 3.**
*Block representation of the smart wearable device with connections to individual subsystems.*

The physical presentation of the smart wearable device is depicted in **Figure 4**. The device is implemented on a four-layer FR4 PCB (printed circuit board) with 1 mm thickness. The physical dimensions are 20 × 29.5 × 7.2 mm (W × L × H) including the battery. It weighs 5.8 g, and because of its miniature size, it can easily be placed under a sweatband. The top layer of the PCB is populated by a microcontroller, IMU unit, FLASH memory, and battery charger. On the bottom side, the power supply, temperature sensor, and the LEDs for pulse rate sensing are placed. Opposite to the USB connector, the RGB LED and the push button are placed. The heart of the smart wearable module is a low power high-performance 8/16-bit RISC microcontroller. It supports 128 kB of FLASH memory, 8 kB of SRAM memory, and 2 kB of EEPROM. It can run with 32 MHz clock (it has an internal calibrated clock source), and it supports various peripheral and communicational interfaces (ADC, SPI, I2C, USB etc.).

To detect and sense tennis strokes, a MEMS inertial measurement unit is used. It incorporates a three-axis accelerometer and a gyroscope, and together, they form a 6-DOF unit (DOF—degrees of freedom). Linear accelerations are measured by

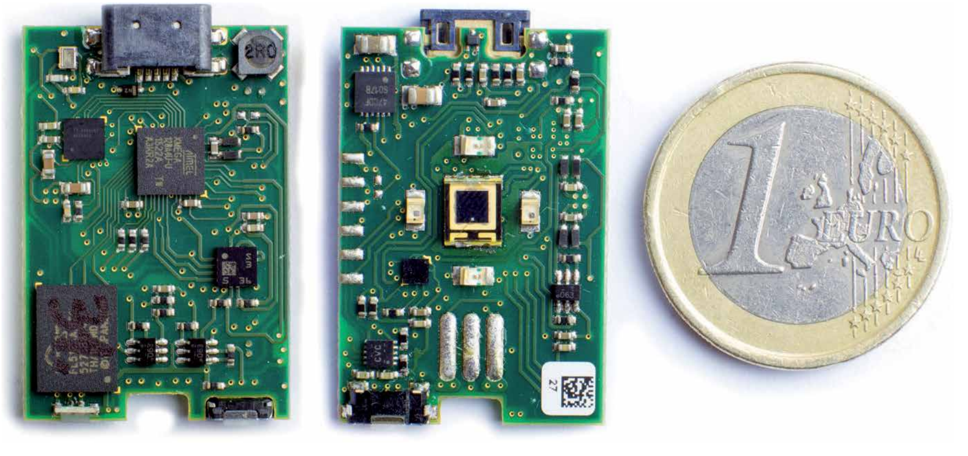

**Figure 4.**
*The physical implementation of the smart wearable module (top and bottom sides of the PCB).*

MEMS digital accelerometer. It supports measuring ranges from ±2 to ±16 G, and it supports 16-bit resolution of output readouts. For angular velocity sensing, MEMS digital gyroscope is used. It supports angular several measuring ranges, from ±125 to ±2000 dps and 16-bit resolution. Due to the integrated 8 kB FIFO memory, burst mode reading of the measured data is possible. This type of readout also helps to reduce the power consumption of the device. For communication with the microcontroller, the SPI digital bus is used. The accelerometer is capable of maximum 6664 sps data rate, and the gyroscope is capable of 1666 sps data rate. Current consumption of the IMU unit is 0.9 mA in normal operation mode and 1.2 mA in high-performance mode. It is placed in a miniature LGA-16L package and because of its miniature dimensions, it is ideal for implementation in the presented smart wearable device.

For sensing the pulse rate of a player wearing the smart wearable device, a pulse rate sensor with integrated analog front-end part is implemented. It has a low-noise receiver with an integrated ADC for reflected signal detection and a LED transmitter. For pulse-rate measurement, it uses a photoplethysmography (PPG). More about the PPG method is presented in Refs [25, 26].

To measure the skin temperature during the sports activity, a contactless temperature sensing is used. The principle is based on IR (infrared) thermopile sensor, which measures the temperature of the surface by detecting the passive infrared radiation with a wavelength from 4 to 16 μm. The accuracy of the used thermopile temperature sensor is ±1°C in the temperature range between 0 and +65°C. Similar integrated circuits are used also in medical contactless temperature measuring devices. The temperature sensor also supports calibration. For this, it has NV-MEM (non-volatile memory), which is used for storing the calibration coefficients. Calibration is necessary in the case when the default emissivity factor is not correct.

For storing the recorded accelerometer and gyro information, external NV-MEM is used with the capacity of 512 Mbits. It is used also for storing the temperature measurements and saving the timestamp data. The memory is large enough to store approximately 1.5 h of non-stop sports activity. When in stroke detection mode (only stroke actions are detected, timestamped, and recorded), it can store approximately 8000 events. This is enough for storing almost 6 h of an average tennis play, where an average of 20 strokes per player per minute is considered [27].

As already mentioned, a USB is used for the connection between the smart wearable module and a personal computer. The connector used must be water-proof due to the exposure to moisture and sweat. For battery management, a dedicated integrated circuit is used. It charges the batter to correct levels, and it also monitors and protects the battery from getting too discharged. This can happen because we use Li-Po battery type, which is sensitive to discharge voltages below 2.7 V (can get damaged). The batter has a capacity of 155 mAh. The charging current is set to 100 mA, which suffices for the battery to be fully charged in approximately 1.5 h.

For more efficient power consumption and achieving longer battery autonomy, power supply switches are implemented. They are used to cut off power to individual subsystems and can reduce the overall current consumption of the smart module. Power switches are P-type MOS-FET transistor with low serial resistance. They are used to distribute power to the IMU unit, PPG measuring subcircuit, the temperature measuring subcircuit, and the external FLASH memory. More about the miniature wearable movement and biometric data acquisition device can be found in [28].

### 2.2 PC application and cloud service

For downloading recorded data from the smart wearable device, a custom PC application was developed. The USB reader is also capable of erasing the module (it erases the internal memory for storing the recorded info), for clock

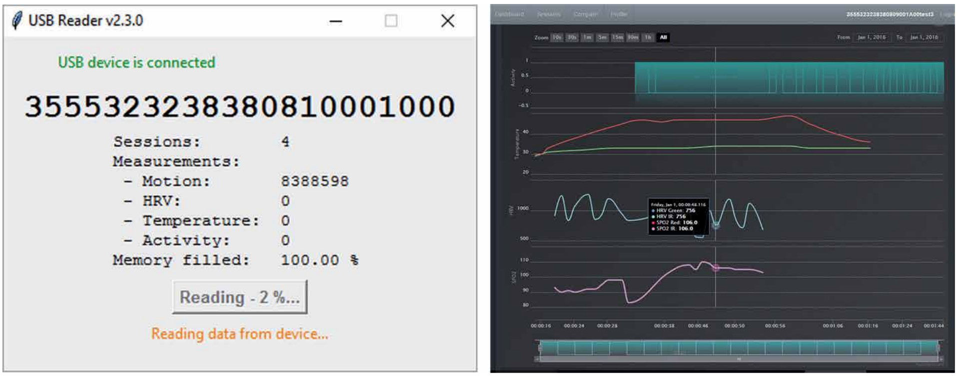


**Figure 5.**
*PC application graphical user interface (left) and cloud service graphical web interface (right).*

synchronization, uploading the data to the cloud, and for eventual firmware upgrades. When the wearable module is connected to the PC, it is detected as a generic HID device. The graphical user interface of the PC application is presented in **Figure 5** (left side).

When the recorded smart wearable data is uploaded to the cloud, it is visualized and processed. Due to the larger processing power being available and bigger memory space, more complex analyses on the recorded data are possible. Comparison of individual athletes is also possible. Because data from several different players and from different events can be stored in the cloud, big data analytics can be performed, and even more, information can be extracted. The visual representation of the proposed cloud service web interface is depicted in **Figure 5** (right side).

## 3. Motion and biometric data acquisition

Details regarding the motion detection and tracking, as well as biometric data acquisition, are covered in the following section. As mentioned earlier, the proposed smart wearable device could be used for several different sport applications, but due to being so miniature and lightweight plus with the battery autonomy of more than 5 h, it is especially suitable for sports like golf or tennis. We chose tennis to test the performance of the proposed system in a real environment. Tests were performed during competitive training. Challenges on tennis stroke detection and classification will also be addressed in this section.

### 3.1 Tennis stroke detection and classification

#### *3.1.1 Tennis stroke detection*

For successful tennis stroke classification process, individual tennis strokes must first be accurately detected. We focused on detecting and classifying the three most common tennis strokes: forehand, backhand, and serve.

**Figure 6** presents the accelerations of individual axes during the tennis game. As expected, there are spikes in accelerometer data for every tennis stroke, where the maximum values of acceleration are usually higher than 10 G (for more powerful strokes like serve the maximum values can reach up to the 16 G). For stroke detection, one could easily compare the acceleration spike values with the predefined threshold. The stroke would then be detected if the acceleration values would surpass it. This is one of the most common methods that researches use for stroke

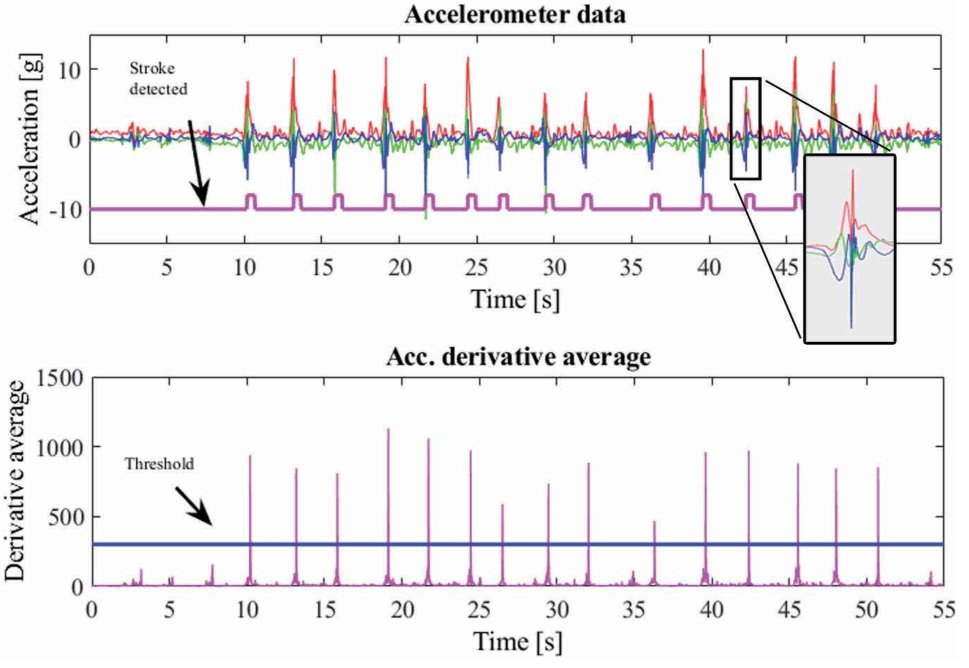


**Figure 6.**
*Graphical representation of the accelerometer data (x-axis = red, y-axis = green, z-axis = blue). The second subplot represents the average derivative of accelerometer data with a predefined threshold for tennis stroke detection.*

detection. The problem with this method is that it can produce false positives because the accelerometer values can be high even during the swing part of the stroke before the ball touches the racket. Therefore, we decide to use a different method for tennis stroke detection. We focused on the point of contact, where abrupt changes in the acceleration readings happen.

The moment of contact can most effectively be detected by calculation a two-point derivative of the acceleration values. We calculate the derivative average for all three axes because rotation normalization is not used. Rotation normalization is usually performed to normalize the acceleration readings orientation between individual players due to the fact that different players hold the racket differently and therefore the axes of the IMU unit are not aligned to the racket in the same way. The following expression is used for derivative average calculation:

$$D[n] = \frac{1}{3} \cdot \sum_{i=1}^{3} \left| [A_i[n] - A_i[n-1]] \right|. \quad (1)$$

where $n$ is the sample data index, $D[n]$ is the average derivative value, and $i$ is the gyro axis index (1 = X-axis, 2 = Y-axis, and 3 = Z-axis). The stroke is detected when the value $D[n]$ exceeds the predefined threshold. Other arm movements can also trigger a tennis stroke detection. By observing **Figure 6**, one can notice small spikes in acceleration between time 0 and 10 s. They happened when the player was picking up the tennis ball with the racket. Acceleration spikes can also occur when the player is twirling the racket during the waiting for the opponent to serve, which is a very common thing [18]. Such events are not actual strokes and are undesirable to be detected. Therefore, the threshold for tennis stroke detection must be selected carefully. It is a tunable parameter and can be adapted to different conditions and different players.

#### *3.1.2 Tennis stroke classification*

We worked on the problem of tennis stroke classification in one of our previous works presented in [29], where we proposed a classification method which is especially suitable for use with small embedded systems with low processing power because it is very simple but effective. The tests were performed on the strokes gathered from several different tennis players. In Kos and Kramberger [28], we extended the database and slightly modified the algorithm for tennis stroke classification. For test and experiments, we used our tennis stroke database (TSD). The database is composed of tennis stroke recordings of seven different players with different levels of tennis knowledge. The recordings were performed on several different occasions and in different conditions (different court surfaces, different tennis balls, and rackets). The recordings are a mix of individual stroke sequences during warm-up and recordings made during competitive training. Overall, the database is composed of 446 strokes. For easier TSD annotation, for each tennis player, a video was recorded in parallel with the wearable embedded device recordings. Other types of tennis strokes are also included in the recordings (e.g., slices, volleys, smashes, etc.), which are not used for tests and in the evaluation.

The main starting point for the tennis classification is that the accelerometer information alone does not have enough discriminative information for the tennis stroke classification task. Therefore, we looked at the gyroscope readings and analyzed them for different tennis strokes. It happens that there is enough difference for simple bit successful implementation for the classification algorithm. The algorithm works in such a way that it first looks for minimum and maximum gyroscope values around the point of contact event (the ball touches the tennis racket strings), and it searches for the axes in which the extreme values occur. The observation interval for minimum and maximum searching is 50 ms before the point of contact event. The gyroscope values for all three axes are sampled and stored in a buffer for maximum and minimum search. When the stroke detection event occurs, the buffer with gyroscope readings is swept for extreme values. Based on the information for which axis and in which direction the extreme value was found, the decision on which stroke happened, is made. For example, if the maximum angular velocity during the swing happened along Y-axis, the stroke is classified as a backhand. If the maximum corresponds to the X-axis, and the minimum is found in the Z-axis, the stroke is classified as a serve. If the maximum and minimum gyroscope values correspond to the X and Y axes, an additional condition is checked for the minimum Z-axis angular rate. If the angular rate is lower than −1500 dps, the stroke is classified as a serve; otherwise, the stroke is classified as a forehand. This condition was added to the classification algorithm because some tennis players tend to rotate the hand differently during the execution of the serve. If none of the abovementioned combinations is true, the detected stroke is classified as unknown (UNKN). This was introduced because sometimes the players make the shots very close to the body or out of balance and are therefore difficult to categorize as one of the basic strokes. The algorithm described is for a right-hand player. For a left-hand player, the accelerations of Y-axis and angular velocities of X and Z axes must be inverted.

### 3.2 Pulse rate and pulse rate variability

To evaluate an athlete's physical and mental levels, pulse rate and pulse rate variability information is recorded during the athlete's activity. For monitoring the pulse rate, we selected the reflective photoplethysmography. The method is noninvasive, and it still gives a good result. Two different light sources with different light wavelengths (RED and IR LED) were used for tissue illumination. The receiving photodiode detects the reflected light. The intensity of the reflection is modulated by the difference in the blood flow; therefore, minimal ripple is present from which the pulse rate can be evaluated. The signal is sampled with 100 Hz. Every heartbeat is represented with a so-called R wave and the distance between individual R waves is called the R-R interval. PR and PRV can be calculated by measuring this interval. Some PR and PRV experiments were performed in our previous work, and the results are presented in [26]. R-R intervals from RED and IR LED illumination are depicted in **Figure 7**.

### 3.3 Temperature measurement

The player's skin temperature was measured with a contactless thermopile sensor. For accurate temperature measurements, the local temperature of the cold-junction temperature reference is measured. This is necessary because this type of sensors can only sense the temperature difference, not absolute temperatures. **Figure 8** presents the skin and module temperature readings during a short practice. For high precision, the sensor must be calibrated because different surfaces have different emissivity (even different skin tones have influence). Plots in **Figure 8** show that the wearable module was slightly heating over time because of the LEDs for pulse rate measurement (they are close to the sensor and they generate heat). This could be the reason that the module achieved a temperature higher than 37°C.

### 3.4 Tennis stroke consistency estimation

Readings of the smart wearable module, if they are stored and properly analyzed, can be used also for the analysis of how consistent a player is when hitting a

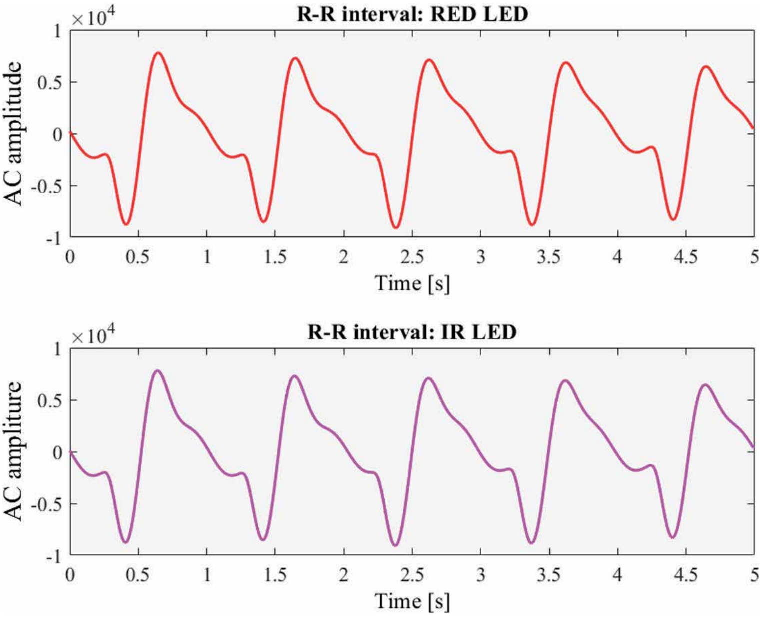


**Figure 7.**
*Graphical representation or R-R intervals obtained with the PPG method. The upper plot represents a signal obtained with red LED tissue illumination and the lower plot represents a signal obtained with IR LED tissue illumination.*

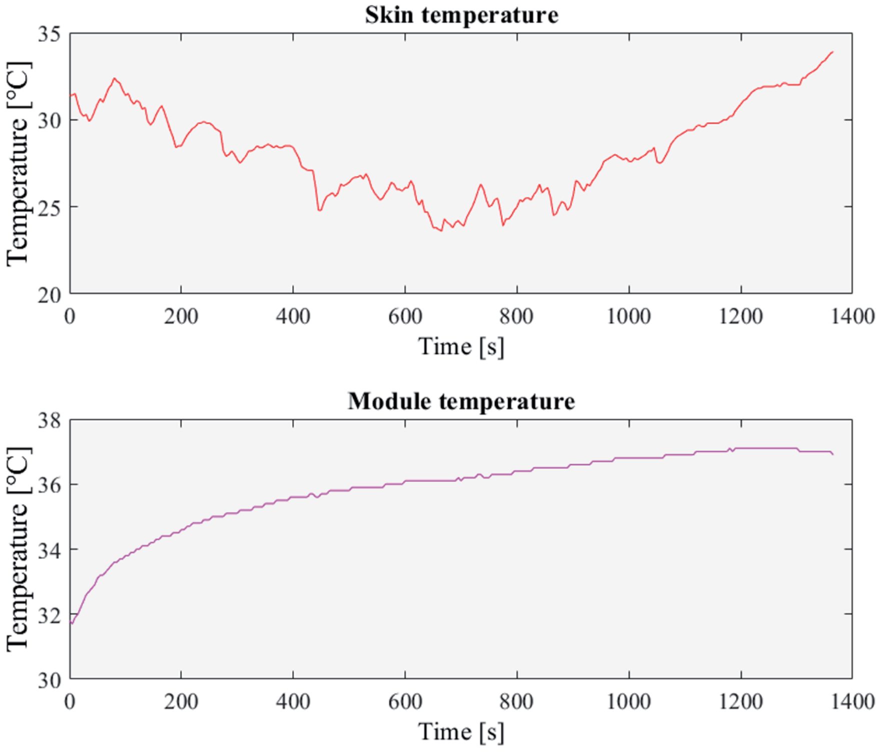


**Figure 8.**
*Temperature readings during a short (20 min) tennis practice. The upper graph represents the temperature of the skin, while the lower plot represents the sensor's internal cold-junction temperature readings.*

stroke. This kind of analysis can be very useful for tennis coaches and other experts on the evaluation of the tennis player's current shape and performance ability. If combined with the information of which stroke was a winner or a fault, even more valuable information can be extracted [30].

### *3.4.1 Forehand stroke models*

For the task of tennis stroke consistency evaluation, we made a general forehand stroke model. A separate model was built for each individual player. The model was made by calculating an average of acceleration sample bins for every accelerometer axis separately. We paid special attention that the accelerometer readings were aligned fairly good with the stroke detection point. About 150 ms before and after, the point of contact was used for making the model. That interval corresponds to 248 sample bins in total. An individual player's forehand stroke model for one axis is determined by using the following expression:

$$FSM(i) = \frac{1}{N}\sum_{j=1}^{N} fh_{acc}[i][j], \quad i = 1{:}248, \tag{2}$$

where $FSM(i)$ corresponds to the axis bin of the forehand stroke model, $fh_{acc}[i][j]$ is an array of accelerometer readings, $N$ is the number of different stroke acc. recordings, $i$ is the index of accelerometer sample bins, and $j$ is the player's stroke record index. For a specific player, the general forehand models (separate for individual axes) are presented in **Figure 9**. The model is seen as the thick line in the middle of the curves.

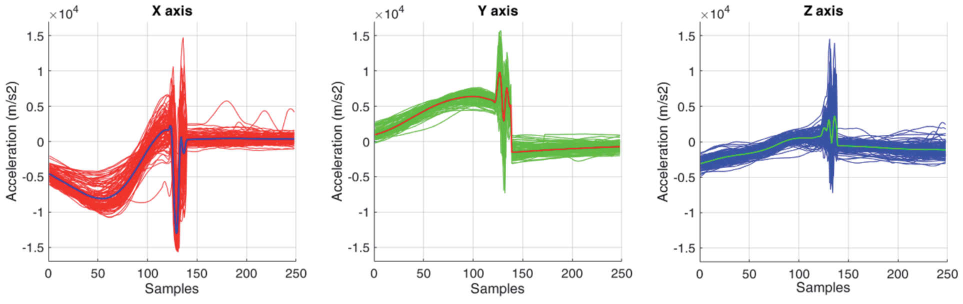


**Figure 9.**
*General forehand stroke model for a tennis player. For each axis, a separate model is presented.*

By observing the acceleration plots, we can notice that the trajectories are quite sparse. If the plots are closer together, then the ability of the player, to hit the strokes in a repeating manner, is very high. In this case, consistency is also very high. From a closer observation of the graphical plots of the individual axis, we can conclude, that the player, whose strokes are presented in **Figure 9**, is the most consistent via Y-axis, where the X-axis is the one with the most scattered plots. This estimation is made on observing the scatter thickness around the thick middle line, which represents the general axis stroke model. Plots show us also the three most obvious swing segments, where at the beginning of the plot from bin 1 to bin 120 is the swing segment. From the bins 120 till 140, the ball impact segment occurs. The last segment, called follow-through is from bins 140 till 248. The thick emphasized line plotted in the middle of the axis's acceleration curves is the graphical representation of a stroke model.

### *3.4.2 Stroke consistency evaluation*

To evaluate the tennis player's forehand stroke consistency, the general player's forehand model is compared to the players' recorded forehand strokes. To be able to derive the forehand stroke models, a database of forehand strokes was built. For estimation of the individual player's forehand consistency, an average distance between individual acceleration bins of stroke recordings and stroke model is calculated. The mathematical expression is:

$$dist(i) = \frac{1}{N}\sum_{j=1}^{N}\left(fh_{acc}[i][j] - FSM[i]\right), \tag{3}$$

where $dist(i)$ is distance (for one axis) between the player's stroke and the stroke model, $FSM[i]$ is the player's forehand stroke model, $fh_{acc}[i][j]$ is the array of player's forehand strokes, $N$ is the number of different strokes, $i$ is the individual stroke sample bin ($i$ = 1:248), and $j$ is the player's stroke record index. Around 100–150 strokes for a player were typically captured.

After that, average value of distances for all the three axes is calculated to get the common distance between the model and the individual stroke recording. Some valuable information is lost by doing that, but the reason for doing it this way is that the sign of the bin differences gets preserved. This is a piece of valuable information which tells us if the player is making the swing "under" or "over" compared to the forehand model. If we would use some other distance metrics (like Euclidean distance) to calculate the distance between acceleration bins of the strokes and the model, the outcome would have an only positive sign and the information about the error direction would be lost. A box plot is used for results presentation. **Figure 10** shows the statistical representation of the forehand stroke consistency for players P1–P9.

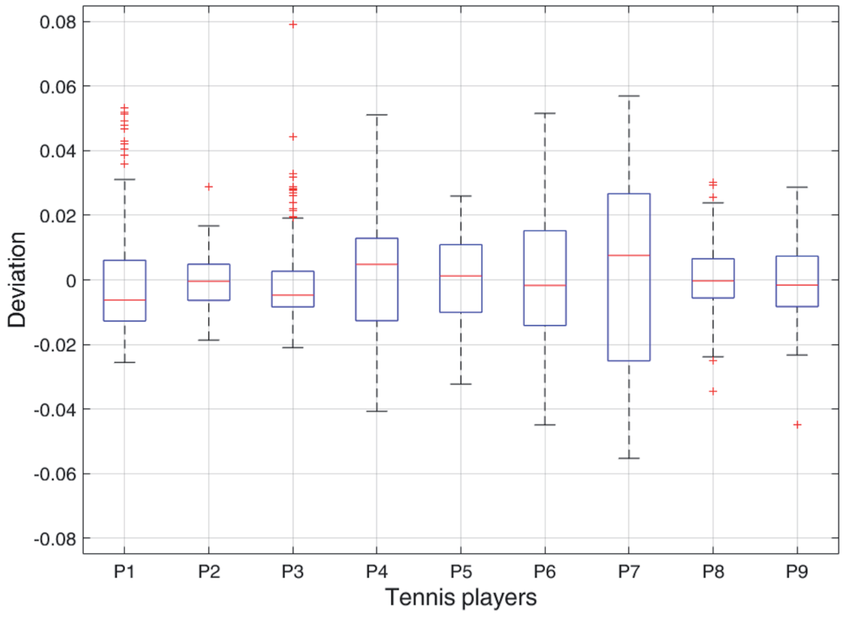


**Figure 10.**
*Box-plot representation of the tennis stroke consistency evaluation. Lower and upper lines of the boxes represent the 25th and 75th percentile of the deviation interval, respectively.*

A comment on the presented data is necessary to properly interpret the provided information. As mentioned, we used a box plot to represent the consistency analysis. A rectangle (box) is presenting each player. The red line in the box represents the average (median) value of the forehand stroke deviation from the model. Players P2 and P8 have near 0 deviation. The upper line of the box represents the 75th percentile of the deviation interval, and the lower line of the box represents the 25th percentile of the deviation interval. His distance (between lower and upper box border) is known also as the interquartile range. Each box is also extended by a line, called a whisker. Whisker is a dotted line that is drawn from the box border to the far border of the observation interval. They are determined beforehand, and in our case, they represent the border for the outlier values. In our case, they are set to 1.5 of the interquartile range. Values of the deviation that exceed this range are represented by red crosses and are called outliers. Box plots in **Figure 10** show that the players P2, P3, and P8 are the most consistent among the tested group because their box plots are the smallest. They have some outliers, but they can be a consequence of an off-balance/close-to-body forehand stroke made. Regarding stroke consistency estimation, the worst player is the player P7. It has the biggest box plot and the red line (average value) is also off center, which suggests that the stroke deviation distribution is somewhat skewed to the positive values.

A more detailed stroke consistency estimation can be made for individual players. In **Figure 11**, detailed segmental stroke analysis is presented, also using a box plot.

As we can conclude from **Figure 11**, detailed segmental stroke analyses for players P4 and P7 are presented. The analyses presented in **Figure 10** gave us the overall forehand swing consistency estimation. On the other hand, the segmental analysis presented in **Figure 11** gives us the insight in which part of the forehand stroke the players are the most or the least consistent. We can see that player P4 has the highest box plots at segments 12–14, which are the segments, where the racket contacts the tennis ball. This deviation in this segment is to be expected and is common because of the oscillations and vibrations due to the ball contact. But the player P7 has the

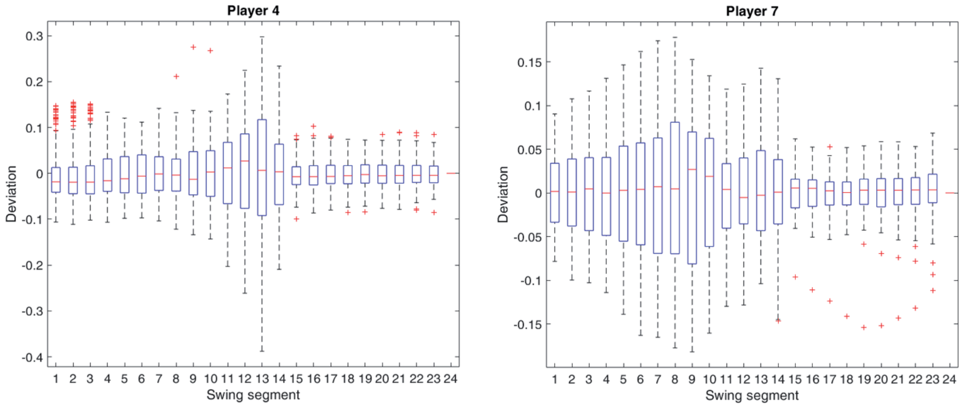


**Figure 11.**
*Segmental forehand swing consistency analysis presentation for players P4 and P7. Player P7 is inconsistent in the swing phase of the tennis stroke.*

least inconsistent forehand around the segments 7–10, which is a swing stage of the tennis stroke. This information can be valuable for the player and the tennis coach. Based on such analyses, they can make a strategy on how to improve the training and performance of a tennis game.

## 4. Conclusion

In this chapter, smart wearables in sport were presented, using a case of a system for tennis game analysis. A miniature wearable device for detecting and recording the movement and biometric data is presented in detail, along with the procedures and algorithms for tennis stroke detection and classification. The presented system also incorporates a cloud service for information visualization and possibly more sophisticated game/athlete's performance analysis. The performance of the proposed system was tested for tennis. The wearable device supports tennis stroke detection and classification of the three most basic strokes: forehand, backhand, and serve. It also supports pulse-rate measurements and skin temperature measurements. A principle of tennis stroke consistency evaluation was also presented. The smart wearable device with cloud processing support and presented stroke analyses can give an athlete or a coach a good insight into an athlete's skills and abilities and can be a great tool for sport performance improvements.

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Chapter 6

# Machine Learning in Wearable Biomedical Systems

*Muhammad E.H. Chowdhury, Amith Khandakar, Yazan Qiblawey, Mamun Bin Ibne Reaz, Mohammad Tariqul Islam and Farid Touati*

## Abstract

Wearable technology has added a whole new dimension in the healthcare system by real-time continuous monitoring of human body physiology. They are used in daily activities and fitness monitoring and have even penetrated in monitoring the health condition of patients suffering from chronic illnesses. There are a lot of research and development activities being pursued to develop more innovative and reliable wearable. This chapter will cover discussions on the design and implementation of wearable devices for different applications such as real-time detection of heart attack, abnormal heart sound, blood pressure monitoring, gait analysis for diabetic foot monitoring. This chapter will also cover how the signals acquired from these prototypes can be used for training machine learning (ML) algorithm to diagnose the condition of the person wearing the device. This chapter discusses the steps involved in (i) hardware design including sensors selection, characterization, signal acquisition, and communication to decision-making subsystem and (ii) the ML algorithm design including feature extraction, feature reduction, training, and testing. This chapter will use the case study of the design of smart insole for diabetic foot monitoring, wearable real-time heart attack detection, and smart-digital stethoscope system to show the steps involved in the development of wearable biomedical systems.

**Keywords:** machine learning, wearable medical devices, real-time detection, sensors for wearable devices

## 1. Introduction

Healthcare is one of the most crucial application areas that require faster development. In the wearable medical device domain, there is a lot of scope of research and development. With the recent technological development, wearable medical devices become feasible for real-time monitoring and diagnosis of medical problems. It has been accelerated with the availability of cheaper component and advancement in wireless communication technology, which has also enabled the application of the Internet of Things (IoT) in the wearable biomedical applications. According to a report by Grand View Research Inc. [1], the Internet of Things (IoT) penetration in the health sector is expected to reach a volume of approximately $ 409.9 billion by 2022. Thus, there is a huge boom in the wearable industry. There is a wide range of wearable devices that transmit medical information to mobile and web applications over the wireless network, enabling remote health monitoring. The wearable medical devices face the challenges of reliability, accuracy, precision, and robustness [2]. There are two important sub-sections for a complete wearable medical device—(i) hardware, which involves the sensor selection and characterization, noise removal from the acquired signals, and communication to the decision-making subsystem and (ii) software, which involves taking decisions based on the acquired signals. The second subsystem is where the machine learning comes into play, and the recent outburst of development in the field of machine learning has increased the possibility of remote monitoring and diagnosing with the acquired data from the wearable devices. The machine learning block of the wearable devices involves various steps such as preprocessing, feature selection, training on the labeled dataset, and testing to verify its accuracy and competency. The various parts of the machine learning block will be discussed in details later in this chapter. Thus, it is inevitable that machine learning methods that include algorithm training are required to enable the diagnosis of different diseases. Examples of success in machine learning lead researchers to the adoption of neural networks and other classifiers for medical diagnostic applications. However, this requires ground truth in the form of accurately curated data sources from carefully constructed subject trials with a properly distributed subject population of significant size. Limitations in ground truth data may lead to inaccurate results from the classifiers. This also includes a novel set of challenges for the design and execution of subject trials that are essential in the development and training of algorithms, as well as verification of system performance. Different open-source databases were used for hardware evaluation. The chapter is intended to provide a guidance to the researchers in computing for healthcare who wish to adopt the compelling mission of wearable device development for healthcare diagnostics.

The chapter draws from the experience in the development of a series of biomedical devices from primary research done in the field of wearable devices for monitoring heart attack, abnormal heart sounds, gait analysis in diabetic foot monitoring, and blood pressure estimation using photoplethysmogram (PPG) signal. Therefore, in this chapter, four major health issues were discussed and how these issues can be well monitored without visiting hospital facilities were discussed. These experiments from various previously performed case studies by the team can help in providing a step-by-step roadmap on how to develop intelligent wearable biomedical system. Section 2 discusses the sensor selection and characterization process for a smart insole for gait analysis in diabetic foot monitoring. Section 3 discusses a case study, how continuous blood pressure can be estimated very accurately using PPG signal with the help of machine learning algorithm. Section 4 shows a wearable device for heart attack detection for the driver in a vehicle environment using classical machine learning approach, while Section 5 describes a wearable monitoring device, which is developed for heart sound monitoring to identify cardiovascular abnormality. Section 6 discusses the key contributions of the chapter along with the major results and their applications in real world. Finally, Section 7 concludes the chapter.

## 2. Smart insole for gait analysis

Gait analysis is an important feature for diabetic foot monitoring. A force between the foot and ground, called the vertical ground reaction force (vGRF), can be acquired using different wearable sensors such as force sensors, strain gauges, magneto-resistive sensors, accelerometers, gyroscopes, and inclinometers or using different type of instruments such as force plate system and multi-camera-based system. Despite the improvements in technology, the cost of the multi-camera setup is high and it requires a long post-processing time. Furthermore, the number of strides that can be captured is limited, making it not applicable for personal use. Some efforts from different research groups have been made to overcome the limitations of traditional force plates by equipping treadmills with few force plates [3]. However, treadmills impose restrictions as subjects cannot change their direction of walking. Therefore, an increase in research interest was observed toward the development of smart insoles, where wearable sensors can be employed to detect vGRF, joint movements, acceleration of lower extremities, and other gait variables [4]. Smart insole provides the researchers with a flexible, portable, and comfortable solution for vGRF measurement. It includes different features including monitoring, processing, and displaying plantar pressure using pressure sensors embedded in the insole.

**Figure 1** shows the complete block diagram of such a wearable system, where the pressure sensor array is placed in a customized shoe above the control circuit. Pressure data have to be digitized in the insole subsystem before it is send via a Bluetooth to a host computer for post-processing and analysis. This subsystem is powered by a battery alongside a power management unit. Pressure data can then be analyzed to extract various gait characteristics for different gait applications.

In this section, the design of smart soles to detect vGRF during gait, with two different types of low-cost commercial force sensor: FSRs and flexible piezoelectric sensors (**Figure 2**), is discussed. All the sensors can be calibrated, details of which can be found in [5], where a simple low-cost calibration method based on load cells has been shown to mitigate the need of expensive calibration devices or Motion Analysis Lab as a calibration reference.

As shown in **Figure 3**, the most common places of foot plane where most of the pressure is exerted during gait are heal, metatarsal heads, hallux, and toe. These are the places where the calibrated sensors are to be placed on the smart insole.

In each insole, 16 sensors were positioned to record pressure values in different locations of the foot sole as shown in **Figure 3b**. Since people typically do not exert pressure on the Medial arch area, there is no sensor placed in this area [8]. Sixteen FSRs/piezoelectric sensors were used to collect data from smart insole, as can be seen in **Figures 4** and **5**. Sixteen inputs were multiplexed to one output through a 16-to-1 multiplexer, then applied to an ADC input of the microcontroller, and sent to host computer. The acquisition circuit was connected to the microcontroller module using an insulated ribble cable to minimize wire path and electrical hazard. The instrumented insole was placed on the top of the insole of the user's shoe to acquire pressure data while the other end of the ribbon cable is connected to a small box with an adhesive strap to wrap around the leg. Real-time pressure data from different sensors were collected in the microcontroller and sent to a PC using

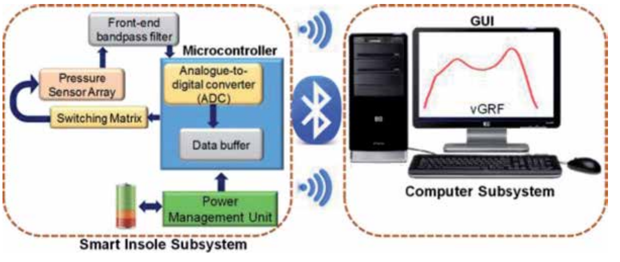


**Figure 1.**
*Block diagram for a diabetic foot monitoring smart foot sole.*

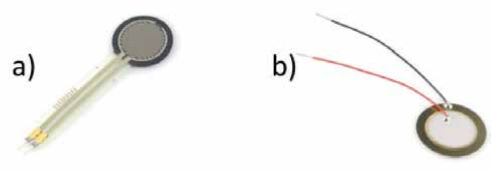


**Figure 2.**
*(a) FSR sensor (Interlink Electronics) [6] and (b) piezoelectric sensor (Murata Manufacturing Co.) [7].*

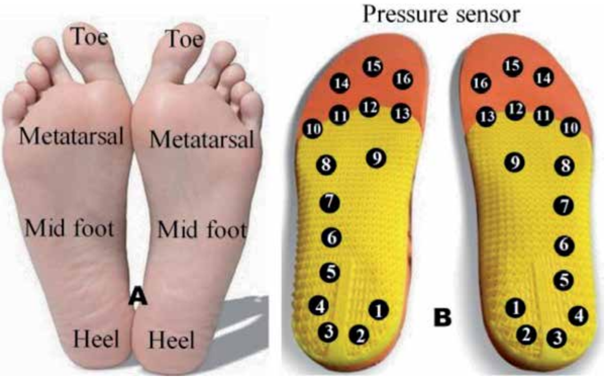


**Figure 3.**
*Selected foot area for pressure acquiring (a) and array of pressure sensor (b).*

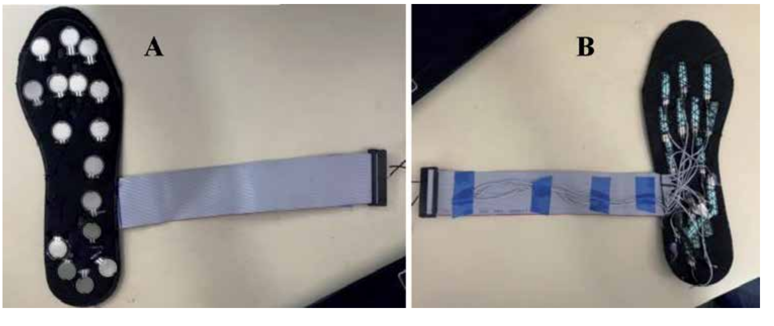


**Figure 4.**
*FSR-based smart insole: top (a) and bottom (b).*

Bluetooth low energy interface, and in the PC, a graphical interface was used to display and analyze the signal.

A commercial smart insole system called F-scan, which is one of the best insoles currently available in the market, was used to validate the performance of the designed smart insole (**Figure 6a**). The F-scan system is designed with very thin flexible printed circuit board with 960 sensing points, and each point can measure pressure with eight-bit resolution with a sampling frequency of maximum 750 Hz. However, the F-scan system is very expensive; the wired system costs around $13,000, while the wireless systems costs around $17,000. On the other hand, the proposed instrumented insole costs only ~500$. Typically the vGRF peak is only 10% of the subject's weight. So, the data were calibrated based on the subject's weight. The subject is supposed to stand on one foot for few seconds while wearing the smart insole, and the pressure is calculated for the purpose of calibration. If the subject's weight is higher than the pressure measured, the calibration was done by a calibration factor greater than 1 while the calibration factor is less than 1 for

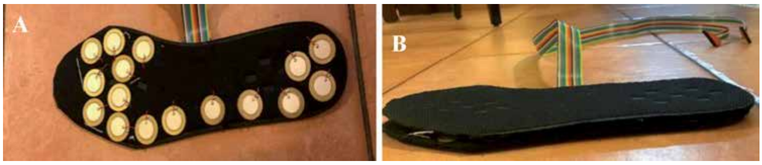


**Figure 5.**
*(a) Piezo insole with 16 piezo sensors and (b) additional insole layer placed on the top of piezo insole to ensure comfortability.*


**Figure 6.**
*Commercial F-scan smart insole (a), subject 01 is wearing the F-scan system (b), and FSR-based prototype system (c).*

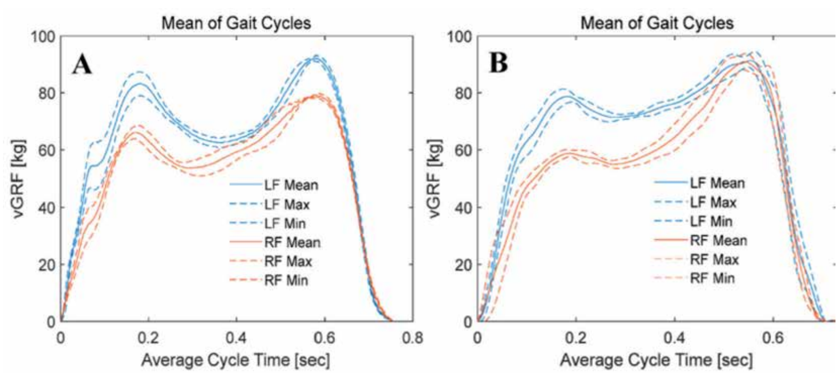


**Figure 7.**
*Comparison between the mean and standard deviation of vertical ground reaction forces (vGRFs) from left (blue) and right (orange) foot using F-scan system (a) and FSR-based system (b).*

patient's weight less than the applied pressure. Calibration factor was calculated in the similar way for the FSR insole. **Figure 6b** and **c** show the application of F-scan and FSR-based system on the same subject while acquiring the vGRF signal.

The FSR-based smart insole can acquire high-quality vGRF for different gait cycles, as seen in **Figure 7**, and it was found that the flexible piezoelectric sensors were performing poor in calibration due to their sensitivity to 3D forces requiring special force calibration machines to control the applied force in x, y, or z directions. Therefore, piezoelectric sensors cannot be utilized as a substitute for FSR in designing smart insole. However, the piezoelectric sensors if calibrated properly can be used to detect the starting and ending of each gait cycle.

## 3. Estimating blood pressure from the photoplethysmogram signal

It is very important to monitor the blood pressure as high blood pressure puts a huge amount of strain on the arteries and the heart, resulting in increase in the probability of clogging of lumens. This clot (clogging of lumens) may cause several health problems such as heart attack, stroke, kidney diseases, and dementia. Thus, continuous blood pressure monitoring, at least four times daily at regular intervals, is preferable. Photoplethysmography (PPG) can be used for measuring the amount of light absorbed or reflected by blood vessels in the living tissue which can be extended to different aspects of cardiovascular surveillance including identification of blood oxygen saturation, heart rate, BP estimation, cardiac output, respiration, arterial aging, endothelial control, microvascular blood flow, and autonomic function. PPG waveforms generally have three distinct features—systolic peak, diastolic peak, and a notch in between—as shown in **Figure 8**.

This section will discuss how the less cumbersome method of PPG signal acquisition can be used in estimating blood pressure, details of which can be found in [9]. This section will also discuss how a trained network using reliable labeled dataset can be used in such a study.

### 3.1 Dataset

The dataset used in this study was taken from Liang et al. [10], which is publicly available. The dataset contained 657 PPG signal samples from 219 subjects. PPG signals were first assessed to check the signal quality and then randomly divided into two sets. Then, 85% of the data were used for training and validation, and 15% of the data were used for testing the performance of the model. The PPG signals were preprocessed before they were sent for feature extraction. After extracting meaningful features, feature selection techniques were used to reduce computational complexity and the chance of over-fitting the algorithm. The features were then used to train machine learning algorithms. The best regression model was selected for SBP and DBP estimation individually. In the quality assurance process, 222 signals from 126 subjects were finally kept for this study. **Figure 9** shows the sample PPG signal which was divided into fit and unfit for the study.

### 3.2 Normalization and filtration

To extract meaningful information from the signals, it was necessary to normalize all the signals. The Z-score technique was used to normalize the signals in this study to get amplitude-limited data. The normalized signal is passed into a low-pass Butterworth filter to remove the high frequency that is acquired by the signal.

### 3.3 Baseline correction

The PPG waveform is commonly contaminated with a baseline wandering due to respiration at frequencies ranging from 0.15 to 0.5 Hz. Therefore, it is very important that the signal is properly filtered to remove the baseline wandering but that important information is preserved as far as possible. A polynomial fit was used to find the trend in the signal and subtracted to get the baseline corrected signal, as shown in **Figure 10**. The next step is to extract features from the preprocessed signal.

### 3.4 Feature extraction

The block diagram summarizing the feature extraction details adopted in the study is shown in **Figure 11**. A PPG waveform contains many informative information such as systole, diastole, notch, pulse width, and peak-to-peak interval. Some of the

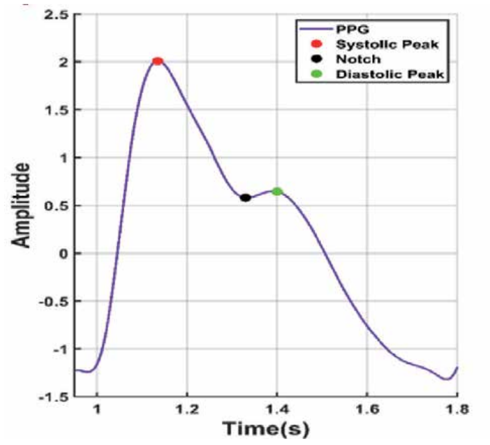


**Figure 8.**
*A typical photoplethysmography (PPG) waveform with notch, systolic peak, and diastolic peak.*

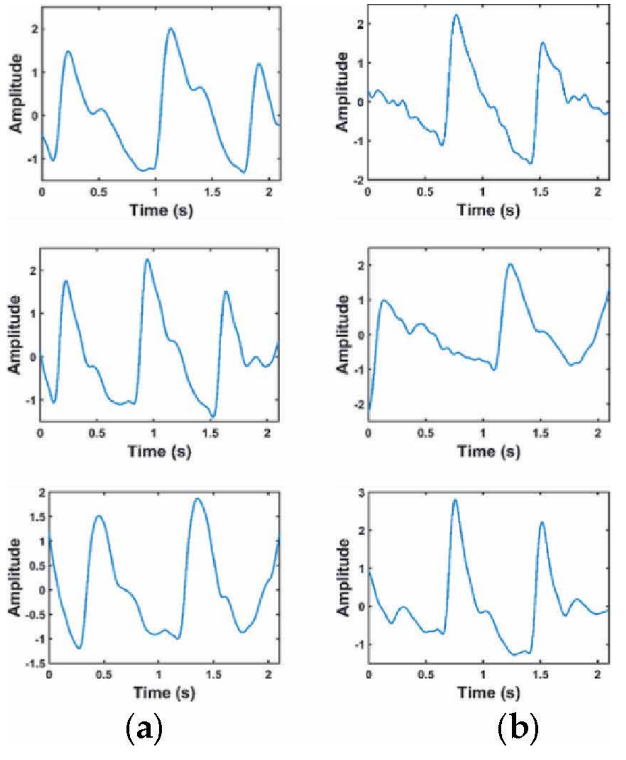


**Figure 9.**
*Comparison of waveforms that are fit and unfit for the study. (a) Fit data and (b) unfit data.*

distinctive features of the PPG waveform might not be dominant in some patients, such as the notch prevalence changing with age.

### 3.5 Feature reduction

Feature selection or reduction is important to reduce the risk of over-fitting the algorithms. In this section, three feature selection methods: correlation-based

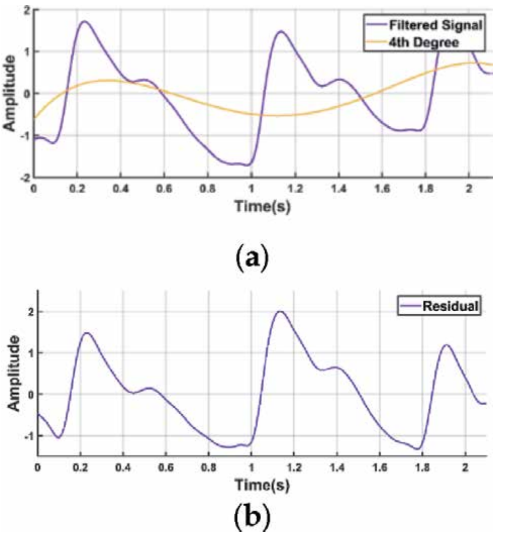


**Figure 10.**
*Baseline correction of PPG waveform. (a) PPG waveform with the baseline wandering and fourth degree polynomial trend and (b) PPG waveform after detrending.*

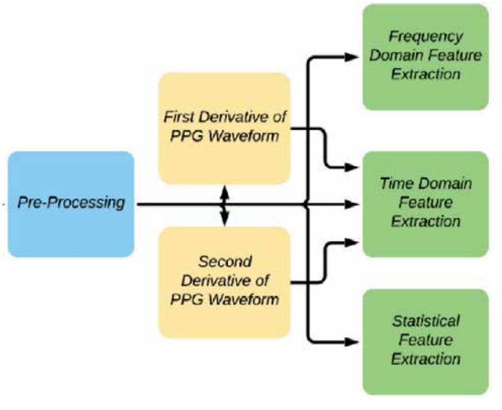


**Figure 11.**
*Overview of feature extraction.*

feature selection (CFS), ReliefF features selection, and features for classification using the minimum redundancy maximum relevance (fscmrmr) algorithm is discussed. ReliefF is a feature selection algorithm, which randomly selects instances and adjusts the weights of the respective element depending on the nearest neighbor. Correlation is a test used to evaluate whether or not a feature is highly correlated with the class or not highly correlated with any of the other features. On the other hand, the fscmrmr algorithm finds an optimal set of features that are mutually as dissimilar as possible and can effectively represent the response variable. The algorithm minimizes a feature set's inconsistency and maximizes the relevance of a feature set to the answer variable. MATLAB built-in functions can be used for CFS, ReliefF, and fscmrmr feature selection algorithms.

After the features were extracted, the feature matrix was trained with machine learning algorithms. The Regression Learner App of MATLAB 2019b was used to estimate the BP. Five different algorithms [linear regression, regression trees, support vector regression (SVR), Gaussian process regression (GPR), and ensemble trees] with their variations to a total of 19 algorithms were trained using the 10-fold

| | | Systolic blood pressure | | Diastolic blood pressure | |
|---|---|---|---|---|---|
| **Selection criteria** | **Performance criteria** | **Optimized GPR** | **Optimized ensemble trees** | **Optimized GPR** | **Optimized ensemble trees** |
| Features from the literature | MAE | 6.79 | 12.43 | 4.49 | 8.17 |
| | MSE | 180.99 | 231.15 | 70.06 | 104.45 |
| | RMSE | 13.45 | 15.20 | 8.37 | 10.27 |
| | R | 0.79 | 0.73 | 0.74 | 0.57 |
| All features (newly designed and from the literature) | MAE | 3.30 | 10.886 | 2.81 | 7.96 |
| | MSE | 72.95 | 264.24 | 30.70 | 111.97 |
| | RMSE | 8.54 | 16.25 | 5.54 | 10.58 |
| | R | 0.92 | 0.67 | 0.90 | 0.56 |
| ReliefF | MAE | **3.02** | 11.32 | **1.74** | 5.99 |
| | MSE | **45.49** | 284.69 | **12.89** | 62.04 |
| | RMSE | **6.74** | 16.84 | **3.59** | 7.88 |
| | R | **0.95** | 0.65 | **0.96** | 0.78 |
| FSCMRMR | MAE | 6.11 | 14.65 | 6.80 | 8.22 |
| | MSE | 108.96 | 321.63 | 77.26 | 110.84 |
| | RMSE | 10.44 | 17.93 | 8.78 | 10.53 |
| | R | 0.88 | 0.58 | 0.72 | 0.56 |
| CFS | MAE | 12.95 | 16.27 | 7.59 | 7.89 |
| | MSE | 361.96 | 448.25 | 108.43 | 106.72 |
| | RMSE | 19.02 | 21.17 | 10.41 | 10.33 |
| | R | 0.50 | 0.28 | 0.57 | 0.58 |

**Table 1.**
*Evaluation of the outperforming algorithms for estimating systolic blood pressure (SBP) and diastolic blood pressure (DBP) after optimization.*

cross-validation. Out of all these algorithms, two best performing algorithms, Gaussian process regression and ensemble trees, were tested.

### 3.6 Results

To evaluate the performance of the ML algorithms for estimating BP, it is important to select proper metrics, i.e., four in this case and are stated below. Here, $X_p$ is the predicted data while the ground truth data is X and n is the number of samples.

$$\text{Mean absolute error, MAE} = \frac{1}{n}\sum_{n}\left|X_p - X\right| \tag{1}$$

$$\text{Mean squared error, MSE} = \frac{\sum\left|X_p - X\right|^2}{n} \tag{2}$$

$$\text{Root mean squared error, RMSE} = \sqrt{\frac{\sum\left|X_p - X\right|^2}{n}} = \sqrt{\text{MSE}} \tag{3}$$

$$\text{Correlation coefficient, } R = \sqrt{1 - \frac{\text{MSE}(\text{Model})}{\text{MSE}(\text{Baseline})}} \tag{4}$$

where $\text{MSE}(\text{baseline}) = \frac{\sum \left| X - \text{mean}(X) \right|^2}{n}$

When using the Regression Learner App in MATLAB, the above criteria are automatically calculated by MATLAB and these values can be used to evaluate the performance of the algorithms.

In **Table 1**, it can be noticed that the ReliefF feature selection algorithm produced the best result when combined with GPR. The feature selected using a combination of ReliefF and GPR performed the best in estimating SBP, while CFS and GPR performed best for DBP. Moreover, R scored 0.74 and 0.68 for SBP and DBP, respectively, which means that there is a strong correlation with the predictors and the ground truth.

## 4. Wearable real-time heart attack detection

Myocardial infarction (MI), commonly known as heart attack, is considered one among the reasons of human death and disability worldwide. Although a heart attack is life threatening, it has early symptoms and signs that could be measured to help save many lives and to avoid consequences. There are three types of a heart attack: STEMI, NSTEMI, and coronary spasm, refer **Figure 12**.

Several ECG ambulatory monitoring systems are available, but they require time and effort to acquire ECG signals from patients. Furthermore, the ECG data have to be sent to professionals for diagnostic analysis. A wearable ECG device can be a solution to acquire real-time ECG signals from the patient. Then, signals are interpreted using built-in algorithms to observe abnormality events of ECG signals and sudden heart attack. Therefore, proper action can be made.

In terms of algorithm, some systems used linear classification and support vector machine (SVM). Some research studies have used the PhysioBank MI database to develop SVM-based real-time MI detection system with a classification accuracy of 90%. Another work came up with the solution for the motion artifact correction for the two-electrode ECG system with an optimized adaptive filter.

In this section, a wearable heart attack detector and alarming system is discussed, which can be used to reduce road accidents that might result from the driver being precipitated by a heart attack, details of which are present in [11]. A portable wearable system that can continuously monitor the heart condition for any early symptoms could inform the patient to pull over the vehicle safely before losing consciousness to avoid potentially fatal consequences. Moreover, medical caregivers could arrive and provide the necessary medical procedures that rescue the consequences of a heart attack.

### 4.1 Wearable system prototype description

The real-time heart attack monitoring wearable prototype system consists of two subsystems as shown in **Figure 13**. The subsystems communicate wirelessly using Bluetooth low energy (BLE) technology.

A wearable sensor subsystem is responsible for real-time ECG signal acquisition, amplification, filtering, digitization, and wireless transmission. The device is attached to a chest belt to be worn by a driver as shown in **Figure 13**. The device

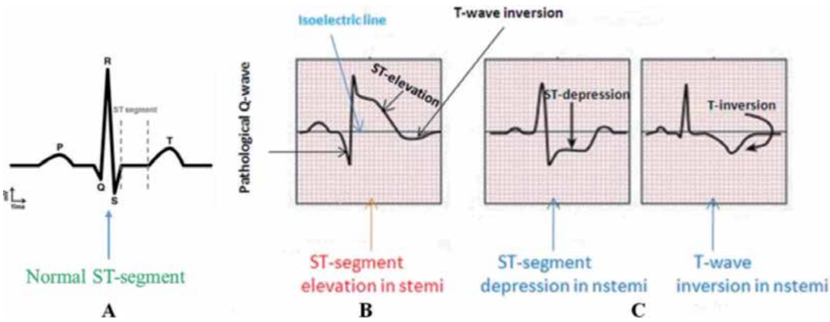


**Figure 12.**
*Comparison of the ST segment variations in a normal subject (a) and in MI patients with STEMI (b) and NSTEMI (c).*

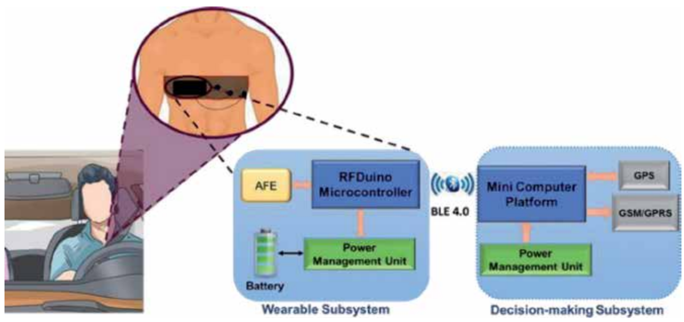


**Figure 13.**
*Block diagram of the wearable heart attack detection prototype.*

includes three dry electrodes (one electrode for reference and two electrodes for differential acquisition) connected to an analog front end (AFE) and an RFduino microcontroller with an embedded BLE module. Furthermore, the designed module incorporates several features to enhance the overall performance including lead-off detection, single-supply operation, adjustable gain control, rail-to-rail output, a three-pole adjustable low-pass filter (LPF), a two-pole adjustable high-pass filter (HPF), and an integrated right-leg drive (RLD). A notch filter in Wien bridge configuration was used to remove the line frequency (50 Hz) from the measured ECG signal. The acquired and preprocessed ECG signal was sent to the decision-making system using BLE.

The intelligent heart attack detection and warning subsystems are trained using the Massachusetts Institute of Technology-Beth Israel Hospital (MIT-BIH) ST Change Database [12]. This subsystem consists of a single board computer, Raspberry Pi 3 (RPi3). The acquired ECG signal from RFduino is delivered to RPi3 over the Bluetooth low energy (BLE) interface. ECG data are buffered for 10 s, and the baseline drift is corrected, segmented to ECG beats (one ECG trace), and smoothened using a digital filter. Furthermore, the subsystem incorporates SIM 908 global system for mobile communications (GSM) and the global positioning system (GPS) module; the module is directly connected to RPi3 using a low power shield.

Twenty-two different machine learning (ML) algorithms were trained for real-time ECG classification. Experiments were done in two stages. In the first stage, the public labeled database "MIT-BIH ST Change Database" covers both normal and abnormal subjects. Twenty-eight subjects' ECG recordings with 14 subjects' ECG recordings were normal, seven patients had T-inversion, and the other patients experienced long-term recordings that showed ST elevation and depression. The system was tested on normal subjects, and an ECG simulator was used to simulate abnormal ST-elevated MI situations to test the performance of the complete system in real time.

### 4.2 Preprocessing

Due to body movements, even respiration, muscle signal, and power line interference of 50 Hz, filtering stage was essential to filter the signal and eliminate the inherent noises. In addition, ECG was often affected by artifacts constituted through electrodes or the interference of the signal processing hardware. Finite impulse response filter (FIR) based on window method was used to smooth the noisy signal by slicing the array of data into selected length windows, computing averages of the data within that range, and maintaining the process throughout the dataset using the moving-average filter.

Baseline wander correction technique and continuous wavelet transformation were used for synthesizing the ECG signal; the wavelet was able to show how the frequency component varied within certain ranges of time. The ECG signals were segmented into traces. A total of 3500 ECG traces over 28 different subjects were considered. Therefore, the total number of ECG traces considered in this study was 10,500.

### 4.3 Feature extraction

Different features were investigated from time, frequency, and time-frequency domains. **Table 2** shows the t-domain, the f-domain, and the (t, f) domain features extracted.

### 4.4 Training process

A five-fold cross-validation technique was used in the testing and training process. Weighted performance matrix was created by averaging the results of all the iterations. The averages of all scoring matrices were calculated for the four iterations along with their standard deviation. Performance evaluations of three different time-frequency distributions (TFDs) were calculated to identify which TFD produced higher accuracy. In addition, the receiver operating characteristic (ROC) analysis was used to evaluate the performance of the ML algorithm for classification confusion matrix and several standard statistical evaluation parameters were used to evaluate the performance of the algorithms including sensitivity, false positive rate (FPR), $F_1$ score, and accuracy.

| Time domain features | Frequency domain features | Time-frequency domain features |
|---|---|---|
| • Mean<br>• Variance<br>• Skewness<br>• Kurtosis<br>• Coefficient of variance | • Spectral flux<br>• Spectral entropy<br>• Spectral flatness | • Combines all the prementioned features<br>• Use quadratic time-frequency distribution (QTFD) to find joint (t, f) representation:<br>a. Winger-Ville distribution (WVD)<br>b. Spectrogram (SPEC)<br>c. Extended modified B-distribution (EMBD) |

**Table 2.**
*Features extracted from the ECG traces.*

### 4.5 Results

All the features listed in **Table 2** were extracted to evaluate the performance of each feature. AUC were calculated as shown in **Table 3**. All features that scored a minimum of 0.5 and above were useful to apply to the classifiers. It was noticed that all the selected features fulfilled the requirement for all of the distributions. Hence, all the features were used for training, validation, and testing. A five-fold cross-validation was used to compute the ML algorithms validation accuracy. **Tables 4** and **5** demonstrate the accuracies resulting from classifying ST elevation and T-wave inversion for the three different (t, f) distributions. Also, both tables showed the two best performing algorithms, the support vector machine (SVM) and the k-nearest neighbors (KNNs). It was noticed that SVM outperformed KNN for the extended modified B distribution.

As shown from **Tables 4** and **5**, EMBD outperformed the others in classifying ST elevation and T-wave inversion. Moreover, the variance showed that the variation for different iterations was at the minimum for the EMBD distribution (**Table 3**). Thus, EMBD distribution was more robust to noisy data. EMBD distributions were implemented for real-time classification using Python. The results showed that both the recall and the precision were reasonable for reliable detection, and for both positive and negative classifications. This can be observed in the F score as well.

| Features | WVD | | SPEC | | EMBD | |
|---|---|---|---|---|---|---|
| | Original | Joint (t, f) | Original | Joint (t, f) | Original | Joint (t, f) |
| Mean | 0.53 | 0.67 | 0.53 | 0.75 | 0.53 | 0.75 |
| Variance | 0.51 | 0.71 | 0.51 | 0.66 | 0.51 | 0.58 |
| Skewness | 0.68 | 0.57 | 0.68 | 0.67 | 0.68 | 0.57 |
| Kurtosis | 0.75 | 0.57 | 0.75 | 0.69 | 0.75 | 0.56 |
| Coefficient of variation | 0.50 | 0.74 | 0.50 | 0.65 | 0.50 | 0.58 |
| Spectral flux | 0.76 | 0.82 | 0.76 | 0.83 | 0.76 | 0.55 |
| Spectral flatness | 0.54 | 0.71 | 0.54 | 0.79 | 0.54 | 0.68 |
| Spectral entropy | 0.81 | 0.71 | 0.81 | 0.65 | 0.81 | 0.59 |

**Table 3.**
*Results of the ROC analysis of the t-domain, f-domain, and (t, f) domain features for the ST elevation detection.*

| Parameters/ML algorithms | WVD | | SPEC | | EMBD | |
|---|---|---|---|---|---|---|
| | SVM | KNN | SVM | KNN | SVM | KNN |
| Recall (TPR) (%) | 92 | 89 | 89 | 90 | 99.1 | 96.7 |
| FPR (%) | 11 | 12 | 14 | 13 | 1.7 | 3.8 |
| Precision (%) | 89 | 88 | 86 | 87 | 98.3 | 96.2 |
| F score (%) | 90.5 | 88.9 | 87.5 | 86 | 98.7 | 97 |
| Accuracy (%) | 87.1 | 86.4 | 85.3 | 84.2 | 97.4 | 95.9 |

**Table 4.**
*Evaluation parameters in classifying ST elevation.*

| Parameters/ML algorithms | WVD | | SPEC | | EMBD | |
|---|---|---|---|---|---|---|
| | SVM | KNN | SVM | KNN | SVM | KNN |
| Recall (TPR) (%) | 86 | 84 | 83 | 84 | 98.5 | 96.9 |
| FPR (%) | 19 | 20 | 22 | 21 | 1.3 | 4.3 |
| Precision (%) | 81 | 80 | 78 | 79 | 97.8 | 95.7 |
| F score (%) | 83.4 | 82.7 | 75.9 | 76.2 | 98.2 | 96.6 |
| Accuracy (%) | 78 | 76.3* | 72.1 | 74 | 96.3 | 95.1 |

**Table 5.**
*Evaluation parameters in classifying T-wave inversion.*

## 5. Real-time smart-digital stethoscope system

Different methods can be used to detect cardiovascular diseases (CVD) including electrocardiogram (ECG), magnetic resonance imaging (MRI), and echocardiogram (echo). ECG is considered the most popular method because it provides an inexpensive, non-invasive, and intuitive method for heart diagnosis. However, it has a limitation when it comes to detecting structural abnormalities and defects in heart valves due to heart murmurs [13]. The previously mentioned technologies for diagnosing cardiovascular diseases could be unaffordable by the majority of the people in low-income countries to detect the CVD in advance [14–16]. Heart sound (HS) has been one of the most primitive and popular methods of detecting early cardiac illnesses with the help of abnormal heart sounds. Phonocardiogram (PCG), also known as heart sound (HS), is a graphical representation of the HS recording signals using an equipment called as phonocardiograph [17, 18]. There are three major limitations of the auscultation of the heart: first, the recorded sounds have very low amplitude which will require the device to be extremely sensitive. Second, the low-amplitude HS signal can be easily corrupted by noise leading to a faulty diagnosis. Finally, the reliability of the auscultation technique mainly depends on the skill, expertise, and capability of hearing of the doctor. Machine learning could be a solution to this problem.

The heart produces HS due to the closure of heart valves that produces the normal heart sounds. Mitral and tricuspid valve closure produces the first heart sound ("S1"), and aortic and pulmonic valve closure produces the second heart sound ("S2") (**Figure 14**). There is no heart sound observed for normal opening of heart valve. Moreover, the flow of blood from one structure inside heart to another typically does not produce any sound. Abnormal heart sounds are caused due to the problems in heart valves or muscles or both. The third HS (S3) (**Figure 14**) is normally caused by a sudden reduction of blood supply from the left atrium to the ventricle, which is normal for children and adults (35–40 years). However, in other age groups and especially in the people above 40 years, it is abnormal [19]. The failure of heart in the diastolic period can be linked to the fourth heart sound as illustrated in **Figure 13**. Heart sounds can be categorized in terms of frequency as they differ from each other in frequency. The frequency of S1 is smaller than S2. The low-amplitude abnormal heart sounds S3, and S4 typically occurs 0.1–0.2 s after S2 and about 0.07–0.1 s before S1 respectively [19]. S1 and S2 sounds are high-amplitude signals and well identified by the diaphragm of the stethoscope. The frequency ranges of S1 and S2 are 50–60 and 80–90 Hz, respectively [19]. S3 is a low-amplitude signal with a bandwidth of 20–30 Hz [19]. S4 typically occurs at the end of diastole and can be identified easily by stethoscope, and the frequency is below 20 Hz [19]. A detailed review and state-of-the-art techniques of HS processing and classification

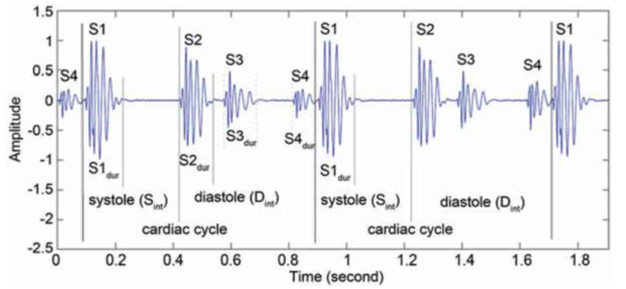


**Figure 14.**
*Different heart sounds.*

are discussed in [20–22]. The abnormal characteristics of the HS signal were stated in [23], while the different signal processing techniques involved in the HS signal analysis are discussed in [24]. In [25], recent works related to feature selection and classification were discussed.

### 5.1 Wearable system

The proposed system consists of two subsystems: the two systems communicate wirelessly via BLE technology as shown in **Figure 15**, details of which are found in [26, 27]. The sensor subsystem consists of the acoustic sensor that acquires the heart sound signal and feeds to analog front end. A custom sensor was designed and implemented on a traditional stethoscope chest piece to amplify the heart sound waveform. The sensor bandwidth is 20–600 Hz to perform the conversion of the heart sound to electrical signal; the microphone was placed in the rubber tube very close to the chest piece as shown in **Figure 16**. The signal is then pre-amplified and filtered. After that, the signal is converted by ADC in the RFduino microcontroller and transmitted wirelessly into an intelligent detection subsystem that consists of personal computer (PC) where the signal will be processed and classified using MATLAB.

In this system, a dataset from PhysioNet challenge 2016 was utilized, which includes 3126 heart sound recordings divided into five databases (A through E); each record lasted from 5 s to just over 120 s. These HS data were recorded from clinical and nonclinical environment from both healthy and pathological patients (e.g., children and adults) from four different locations—aortic, pulmonic, tricuspid, and mitral areas. The dataset includes normal and abnormal recordings with a higher number of normal than abnormal readings.

The brain of the whole system is the intelligent abnormal heart sound and warning subsystem. It is comprised of three modules: data acquisition and logging, Bluetooth module, and classification. This subsystem acquires real-time HS signals and detects the abnormality of the signal using trained ML algorithm. Normal and abnormal heart sound data from a public database were used for training and testing of the machine learning algorithm in the MATLAB environment. The best performing algorithm was identified and ported in Python 3.5 to be used as a real-time classifier in the testing phase. The detailed block diagram of the machine learning approach can be seen in **Figure 16**.

The HS data were preprocessed and segmented into training and testing data. The algorithm to classify MI, the support vector machine (SVM) algorithm, was implemented initially using MATLAB 2018a and later on using Python 3.5 in personal computer (PC) platform for real-time classification. Signal preprocessing was accomplished using the signal processing toolbox, and training and classification

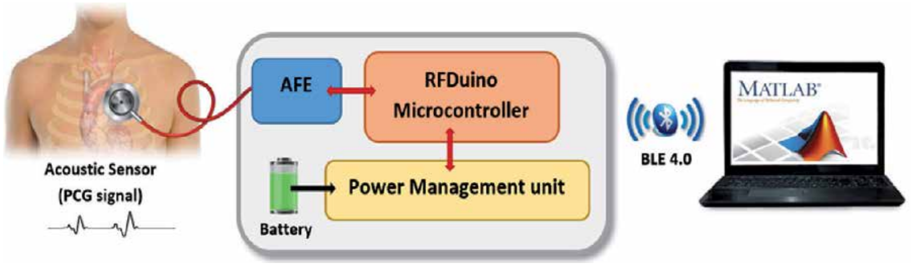


**Figure 15.**
*System overall with modified stethoscope chest.*

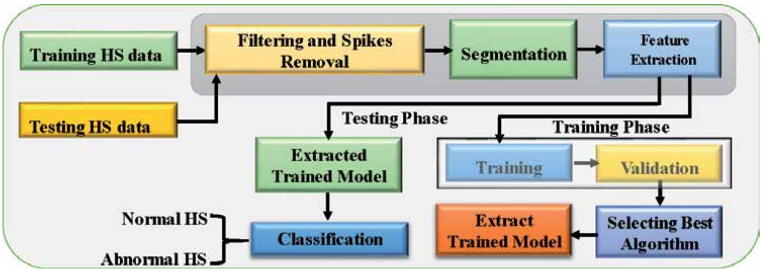


**Figure 16.**
*Blocks of the machine learning-based abnormality detection algorithm.*

were done by Statistics and Machine Learning Toolbox in the MATLAB and using Numpy (v1.13.3), Matplotlib (v3.0.2), PyBrain (v0.31), and Scikit learn (v0.20) libraries in Python.

## 5.2 Preprocessing

In the preprocessing, a sixth-order bandpass IIR filter with lower 3-dB frequency of 20 Hz, higher 3-dB frequency of 600 Hz, and the sample rate of 2000 Hz was used to remove any high or low noise. After filtering, the signal is segmented. Segmentation of the PCG signals into heart cycles and marking of cycle starting instances are very important to generate the epoch of interest for the machine learning.

An automatic code was used to identify the S1 peaks of the PCG signal. One complete cycle of PCG signal is from one S1 peak to another S1 peak. This was segmented along with a time offset to capture the beginning of S1 and the ending of S2 as shown in **Figure 17**. In this study, MIT-BIH benchmark dataset was used and randomly partitioned into two subsets. The first set is for training and validation (80% of data), and the second set is for testing (20% of data). The ML models were trained to classify a two-class problem (normal and abnormal). For evaluation, confusion matrix and standard statistical evaluation parameters for each algorithm were calculated for each fold. After five-fold cross-validation, these parameters were used to evaluate the performance of the algorithms.

For feature extraction, 27 features encompassing t-domain, f-domain, and mel-frequency cepstral coefficient (MFCC) features were extracted for each heart sound cycle. The t-domain features were mean, median, standard deviation, signal twenty-fifth percentile, signal seventy-fifth percentile, signal interquartile range, mean absolute deviation, skewness, kurtosis, and Shannon's entropy, while the f-domain features were spectral entropy, signal magnitude at maximum frequency,

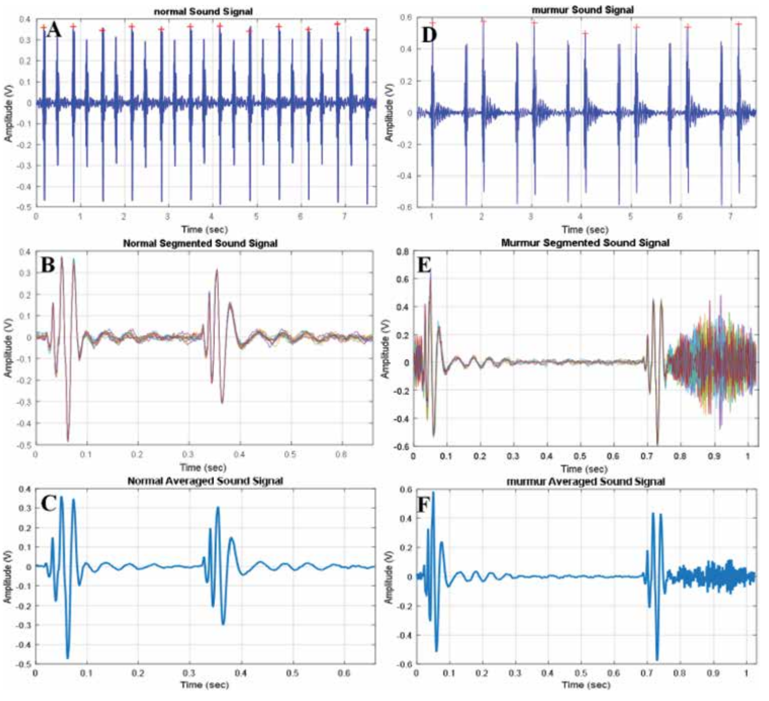


**Figure 17.**
*Normal and abnormal HS: (a and d) detection of peaks; (b and e) overlaid segments; (c and f) average of the segments.*

the maximum frequency in the power spectrum, and ratio of signal energy between the maximum frequency range and the overall signal. Other features were mel-frequency cepstral features.

### 5.3 Feature reduction

Neighborhood component analysis (NCA) is a non-parametric and embedded method for selecting features to provide maximum prediction accuracy of classification algorithms. NCA with built-in functions in Statistics and Machine Learning Toolbox™ of MATLAB was used. It can be noted that 15 features were the most important features out of the 27 features, which were kurtosis, maximum frequency value, and all the MFCC features. In addition, the parameters for the trained model were tuned to optimize their hyperparameters. The best performing algorithms were optimized to calculate the performance measures. Statistical measures were then calculated for the testing dataset (20% of the whole database).

### 5.4 Results

Twenty-two different algorithms [three decision trees, two discriminant analyses, six support vector machines (SVMs), six k-nearest neighbors (KNNs), and five ensemble classifiers] were trained for the testing dataset with 27 features. The validation accuracy and their corresponding performance measures are listed in **Table 6**.

It is obvious from the above table that the best validation accuracy was observed for “Fine Tree” classifier. Moreover, the accuracy of classifying normal is higher than abnormal and this is because of the imbalanced dataset. Therefore, to reduce the potential over-fitting of the features, a reduction in the number of features used in the training process. The training dataset was re-trained with the reduced number of features (15), and all evaluation parameters were calculated. **Table 7** summarizes the evaluation measures for identifying the best algorithm with feature selection.

From **Table 6**, the overall accuracy was reduced as well as classifying normal and abnormal both were also reduced even though the same algorithms were performing best in the classification after feature reduction. Therefore, it can be said that the features used for classification are optimized and cannot be reduced.

To improve the performance of the best performing algorithms by optimizing the hyperparameters of the algorithms, it was observed that the performance of the ensemble algorithm can be improved. Two important parameters were optimized for the ensemble algorithms: "Distance" and "Number of neighbors."

| Items | Fine KNN | Weighted KNN | Ensemble subspace discriminant |
|---|---|---|---|
| Accuracy (%) | 94.63 | 93.72 | 93.17 |
| Accuracy: abnormal (%) | 88, 12 | 85, 15 | 87, 13 |
| Accuracy: normal (%) | 96.6, 3.4 | 97, 3 | 95, 5 |
| Error (%) | 5.37 | 6.28 | 6.83 |
| Sensitivity (%) | 96.32 | 95.24 | 95.67 |
| Specificity (%) | 89.34 | 88.72 | 85.49 |
| Precision (%) | 96.62 | 96.54 | 95.29 |
| FPR (%) | 10.66 | 11.28 | 14.51 |
| $F_1$ score (%) | 96.46 | 95.88 | 95.48 |
| MCC (%) | 85.34 | 82.7 | 81.5 |

**Table 6.**
*Performance measures of three best performing algorithms for full-feature set.*

| Items | Fine KNN | Weighted KNN | Ensemble subspace discriminant |
|---|---|---|---|
| Accuracy (%) | 92.36 | 92.02 | 92.89 |
| Accuracy: abnormal (%) | 84, 16 | 82, 18 | 83, 17 |
| Accuracy: normal (%) | 95, 5 | 95, 5 | 96, 4 |
| Error (%) | 7.64 | 7.98 | 7.11 |
| Sensitivity (%) | 94.85 | 94.30 | 94.77 |
| Specificity (%) | 84.52 | 84.62 | 86.71 |
| Precision (%) | 95.08 | 95.22 | 95.90 |
| FPR (%) | 15.48 | 15.38 | 13.29 |
| $F_1$ score (%) | 94.96 | 94.76 | 95.33 |
| MCC (%) | 79.17 | 78.09 | 80.42 |

**Table 7.**
*Performance matrix for the three best performing algorithms on reduced feature set.*

## 6. Discussion

This chapter summarizes the findings of four different applications of wearable devices to tackle four critical clinical problems. The smart wearable devices reported here can help patients in different settings to manage their diseases, which will reduce frequent hospital visit requirement and can elevate their living standard. The summary of the results from each of the case study can be provided as below.

The FSR-based smart insole can acquire high-quality vGRF for different gait cycles, and it was found that the flexible piezoelectric sensors were performing poor in calibration due to their sensitivity to 3D forces requiring special force calibration machines to control the applied force in x, y, or z directions. Therefore, piezoelectric sensors cannot be utilized as a substitute for FSR in smart insole application.

ReliefF feature selection algorithm produced the best result when combined with Gaussian process regression (GPR) for predicting the systolic and diastolic blood pressure using PPG signal. The feature selected using a combination of ReliefF and GPR performed the best in estimating SBP, while correlation-based feature selection (CFS) and GPR performed best for DBP. It can be noted that this optimized approach can estimate SBP and DBP with the RMSE of 6.74 and 3.57, respectively.

Extended modified B distribution shows the best performance in classifying ST elevation and T-wave inversion in the heart attack detection case study using ECG signals. The variance of the results from EMBD technique showed that the variation for different iterations was at the minimum for the EMBD distribution (**Table 3**). Thus, EMBD distribution was more robust in heart attack detection in case of noisy ECG data.

Heart sound signals can be accurately classified using "Fine Tree" classifier compared with 22 different algorithms [three decision trees, two discriminant analyses, six support vector machines (SVMs), six k-nearest neighbors (KNNs), and five ensemble classifiers]. Feature reduction technique did not help in improving the performance. It was observed that the best performing algorithms can be improved further by optimizing the hyperparameters of the algorithms.

## 7. Conclusion

The chapter discusses in detail with case studies about the different opportunities available in the design and development of wearable medical devices, which can help in real-time healthcare monitoring. The chapter has not only discussed on the study of characterizing sensors for specific wearable device but also how reliable dataset can be utilized to develop trained model for medical diagnosis. It has also shown how to design and develop a complete wearable device with real-time monitoring and alarming in case of emergency. These smart wearable solutions, if properly designed and deployed, can help millions of users to take advantages of the wearable technologies and thereby can monitor their health status in different setting.

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## Conflict of interest

The authors declare no conflict of interest.


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Section 4

# Technological Development

Chapter 7

# Application of Basketball Game Models through Sports Technology

*Artan R. Kryeziu*

## Abstract

The purpose of this chapter is to present the application of basketball game models through sports technology. The chapter contains introduction, terminology, sports technology practices, basketball models through technology, compilation of basketball models in sports technology, and references. In this chapter, there will be other sub-chapters that will be considered in case of depth exploration of the chapter, writing, processing, and modification of data from other authors. We will present realistically the most renowned thinkers and theorists of the field of models and sports technology from which to draw the most practical model of evolution of basketball.

**Keywords:** models, basketball game, sports technology

## 1. Introduction

Nowadays, the technology is inevitably important and is present everywhere. From the simplest daily task to the optimized complexity of training process, technological innovation products which seems to be the current reality we must deal with. Recent years have been quite challenging within this subject in sports context and innovations occurred rapidly. Sensors and mobile applications that control biometric data, video systems that analyses athlete's performance and stadiums that are a showcase of technology are some evidences of the emerging innovations that surround sport community [1].

As modern technology constitutes an indispensable element of modern sports, thus also of basketball, its application is practically without limits, regardless of whether it is used in the teaching process with an emphasis on basketball contents, or in the training process with the youngest basketball players or with top level professionals. In addition, in the process of including new technologies, it is important to educate all the participants included in the process so that they can all independently use these technologies, at least to a certain degree [2]. With the continuous development of informatization, networking and digitization of sports teaching, combing basketball teaching with computer technology and multimedia technology, numerous multimedia teaching course wares of pictures, character, sound and graphic in one have been developed to assist basketball teaching, which effectively improved the basketball teaching [3]. The world of sport is constantly changing due in large part to the integration of technology. Modern science now allows athletes to go higher, move faster, and importantly, stay safer [4, 5]. Technology in sports is a scientific means by which athletes attempt to improve their training and competitive surroundings in order to enhance their overall athletic performance. The real time and rapid feedback systems for collecting and analysis sports data provide innovative and effective support for coaches and athletes [4, 6]. Basketball shooting is one of the most important techniques in basketball. It is the only way to score and it is the key technology in basketball technology, and it is also the core link of basketball tactics. Whatever attack tactics is ultimately to be attributed to the shooting score, while the purpose of defense is to limit the opponent's shooting, so as to create more scoring opportunities for him. So in a sense, the basketball game is a sport that limits the opponent's score by shooting himself [7, 8]. In this chapter will be implemented the application of basketball game models through sports technology.

## 2. Compilation of basketball models in sports technology

### 2.1 Heart rate sensors

Heart rate is an important indicator of bodywork and effort. Therefore, in spite of some limitations, its measurement is a very practical and useful way of monitoring and controlling the workload and effort of athletes in training and competitions. Therefore, in all sports sectors where an important factor of success is sustainability, therefore, heart rate meters are an indispensable and indispensable tool. T. i. The pulse meter (heart rate gauge) is becoming an almost obligatory part of the equipment even in recreational workouts [9]. In modern times there are a large number of measuring instruments on the market, which mainly enable the monitoring of heart rate values, and depending on various scientific, training or educational requirements, they measure several other parameters such as maximum heart rate, energy consumption, covered distance, time spent in a specific workload zone, difference in altitude, etc. [2].

The performance of basketball depends on many factors. Among them, fitness plays a very important role, and within them also maintainability and functional abilities. In 40 minutes of play, the basketball player carries about 4500 m of paths (**Figures 1** and **2**).

The performance of basketball depends on many factors. Among them, fitness plays a very important role, and within them also maintainability and functional abilities. In 40 minutes of play, the basketball player carries about 4500 m of paths with an average speed of just under 2 m/s [10]. The movements they perform are very diverse, varying in intensity and length. According to some authors [11, 12], basketball is 20 to 30% aerobic and 70 to 80% is anaerobic sports activity (**Figure 3**).

Often times students and coaches of basketball systems that in addition to real-time heart rate monitoring for all the players involved in the training process or a game, also enable entering relevant parameters, i.e. workload zones which are determined pursuant to some other protocols (e.g. spiroergometric in laboratory conditions), and based on which more precise intensity levels are individually determined [13]. In common crowds and even contacts between players, we can damage other players with it. This is also the reason that its use is prohibited in the game with rules, and it is often unheard of in trainings between trainers and players. Some players who are not accustomed to using the meter simply disturb it, and thus affect their concentration and accuracy. The next difficulty is that a player often very hardly monitors his heart rate on a small gauge during training, as he is

**Figure 1.**
*The heart rate monitor is a compulsory device in all sports sectors where it is an important factor of performance sustainability. Web source: http://www.polar.fi/polar/channels/eng/.*


**Figure 2.**
*Heart rate monitor manufactured by POLAR (V800) with the corresponding chest strap (H7). Web source: www.polar.com.*

usually burdened with other things to focus on. It is even more closely monitored by the player's heartbeat trainer. The communication between him and the player is, of course, limited, so he closely monitors the heartbeat of the player and his load [9]. This, of course, also means that he cannot respond in a timely manner with the appropriate instructions and instructions to the player. The data from the meter can only be obtained by the trainer after the end of the load, but most often only after the training. A long time ago, a Finnish manufacturer of Polar gauges developed a device, a heart rate measurement system, Team System, which is designed specifically for team sports, and also games from the human. However, this also does not allow immediate feedback or feedback. Online communication between an athlete and a trainer. The data stored on the transponder must be transferred to the computer afterwards using a special interface [9].

### *2.1.1 Wearable tracking devices*

In 2001 the Australian Cooperative Research Centre for Micro Technology, under Project 2.5 "Interface Technologies for Athlete Monitoring," began work to

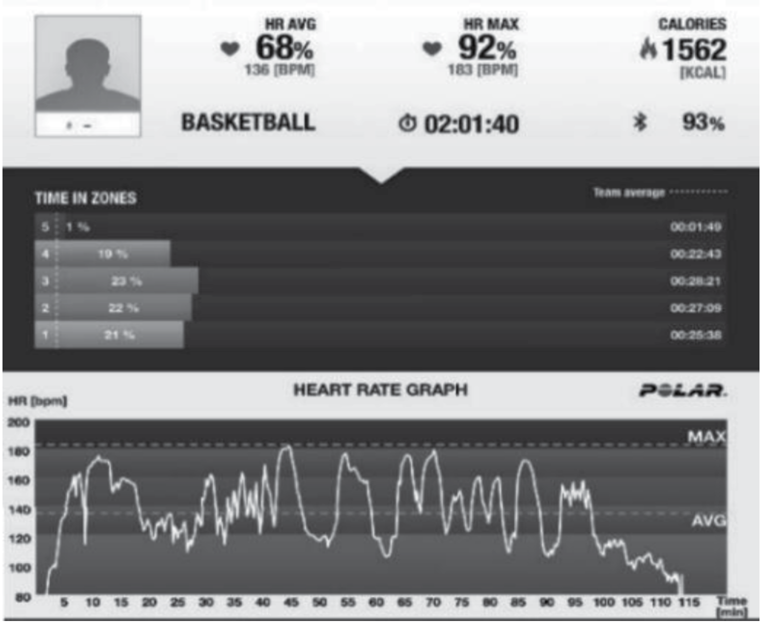


**Figure 3.**
*Digital interface representation of the application program Polar Team. Web source: www.polar.com.*

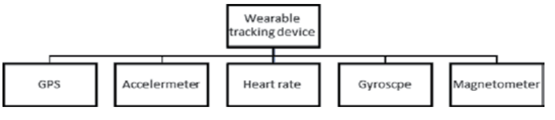


**Figure 4.**
*The five sensors contained within a typical wearable tracking device.*

develop unique and unobtrusive real-time athlete monitoring equipment [14]. Recent years have witnessed further development and the introduction of wearable tracking device. Technology to team sports with a view of providing objective and possibly real-time workload monitoring during training and game-play. Wearable tracking devices often contain multiple sensors (**Figure 4**) in a small, lightweight unit worn by players on their upper (dorsal) body (e.g., the MinimaxX S4 wearable tracking device is 0.088 m× 0.050 m× 0.019 m in dimension weighs 67 g). These devices may include global positioning system (GPS), accelerometer, heart rate (HR), gyroscope, and magnetometer sensors. Thus, time, position, distance, velocity, acceleration, heart rate, angular velocity and orientation can be synchronously recorded.

The GPS component of the wearable tracking device records information in regards to time, distance, position, direction, and velocity. Specifically, the GPS receiver within the device works off a network of satellites to triangulate its position [15]. However, signals from the satellites to the GPS can be influenced by the atmosphere, deviations off various local obstructions (e.g., stadiums), and the number of satellites available to the receiver (four set as a minimum to triangulate the position and altitude of the unit). Therefore, GPS data cannot be collected indoors [16] and are less accurate in enclosed stadiums where team sports are commonly played. Although, newer models have the capability of working off fixed nodes within enclosed stadiums to enable the indoor capture of GPS data (e.g., Optimeye T5, Catapult Innovations, Australia), these Wearable tracking device GPS Accelerometer Heart rate Gyroscope Magnetometer 31 units have only recently been released (end of 2014) and have not been validated. In addition, GPS data cannot be used to quantify the workloads imposed on athletes during low velocity, high intensity movements, such as tackling and bumping in contact sports.

The HR component provides a non-invasive method of measuring HR in team sports [17] and is one of the most commonly used methods to indicate the intensity of exercise [18]. Although accurate in the field [19], HR may be influenced by a number of factors including environmental conditions (temperature, humidity, ambient air), hydration status, altitude [18], state of training, exercise duration, and medication [20].

The application of gyroscopes to human movement analysis is still developing (84). In team sports, the gyroscope provides information about angular velocity or rotation of a player's body (75). As human movement consists of mainly limb rotations around joints (84), gyroscopes are extensively used in gait analysis (75). However, in team sports the wearable tracking device is positioned on the upper body and this may limit its full potential. Gyroscopes are more commonly used in navigation and automotive fields (e.g., by integrating the rate of angular velocity, change in orientation, and direction from the initial reference orientation, direction can be obtained) [19], as well as in consumer products (e.g., anti-jitter compensation in cameras) [20]. A magnetometer measures the direction and strength of a magnetic field [21]. This data is then used to detect the direction of travel [22]. However, local disturbances in the magnetic field caused by electric currents, close permanent magnetic interference, 32 and large iron bodies can significantly affect its measurements [23]. These can also affect the magnetic field angle of inclination (the angle of the earth's magnetic field with respect to the surface of the earth) that is different at various locations around the world [23]. As a result, this sensor is predominantly not used in team sports. Although, research has shown that a combination of technologies such as accelerometers, gyroscopes and magnetometers can improve the accuracy and performance of either technology alone [24]. For instance, accelerometers can compensate the drift of the gyroscope about the axes of the horizontal plane, while magnetometers can do the same for the vertical plane [23]. The most relevant sensor to this thesis is the accelerometer. The accelerometer contained within wearable tracking devices is typically triaxial, samples at 100 Hz and has a range anywhere between ±6.0 to 12.0 g (Figure 2-8). For example, the MinimaxX S4 wearable tracking device contains a triaxial accelerometer (KXD94, Konix, USA) with a sampling frequency of 100 Hz and a range of ±10.0 g (**Figures 5** and **6**).

## 2.2 Diagnostic equipment manufactured by Microgate, IT

The OptoJump testing system is a measuring instrument composed of two identical 1 m-long panels based on optical technology. Each panel contains 96 LEDs


**Figure 5.**
*An accelerometer (left), MinimaxX S4 wearable tracking device (middle), and example sports vest (right). Web source: http://elite-perf.com/.*

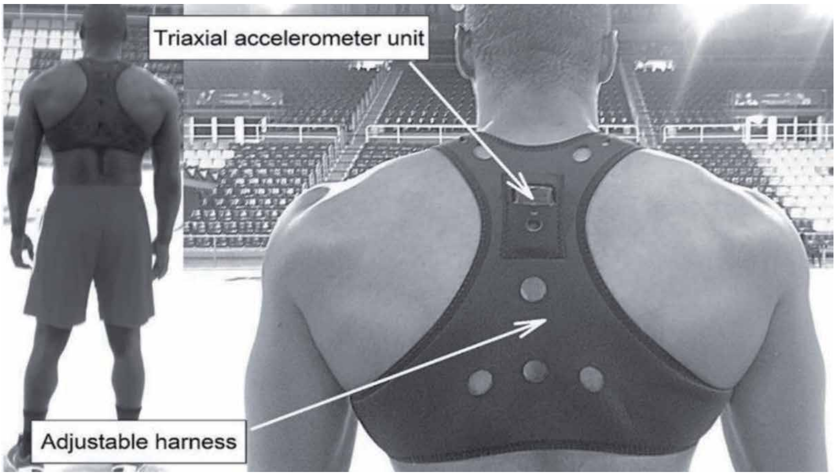


**Figure 6.**
*Triaxial accelerometer unit fitted to the upper back between the shoulder blades of each player using an adjustable harness.*

**Figure 7.**
*Polar developed Team System to measure heart rate in team sports. Web source: http://www.polar.fi/polar/channels/eng/.*

which are all interconnected by the impulses that they transmit. The described system is connected by a USB cable to a portable laptop and it is managed via the OptoJump Next application program [2]. The device itself can primarily be used in diagnostics of various parameters in performing different jumps, such as reflection height, duration of contact with the surface, duration of the jump, etc. It can also be applied for determining specific kinematic parameters in walk analysis (OptoGait) and run analysis. The above mentioned ultimately enables objective diagnostics, as well as implementation of corrective kinesiological operators for the purpose of correcting certain established imbalances, which finally aims at enhancing the locomotor system of children. Considering that explosive leg strength has a significant impact in the specification equation of basketball from the aspect of motor abilities, this instrument can also be used for assessing all the parameters based on which the analysis of the desired results can be performed in assessing explosive leg strength (**Figure 7**) [2].

Likewise, in certain basketball research, this device had been used for assessing certain parameters of performing a jump shot in different variable and situational conditions as a means of observing parameters such as duration of contact with the surface, reflection height, duration of the jump, etc. [2, 12, 25]. The practical value of this instrument is in its mobility and applicability in realistic conditions, as well as in the fact that it can also measure parameters that are manifested during specific movements that players perform in basketball. Considering that explosive leg strength has a significant impact in the specification equation of basketball from the aspect of motor abilities, this instrument can also be used for assessing all the parameters based on which the analysis of the desired results [2]. Moreover, the OptoJump is composed of two video cameras which record a player's motor motion during the performance of a specific test, enabling a standardized analysis of the results obtained from the video recording during subsequent processing. In addition to the above mentioned, in combination with the Gyko device, it allows an assessment of the duration of the concentric and eccentric phase during a basic or specific motor movement. Due to the short duration of the said movements, it is absolutely impossible to obtain the desired results in this sense via subjective assessment. By using video technology, it is also possible, in addition to the obtained data, to analyze the slow movement and detect certain errors, as well as potential improvements. The data can also be presented to the student/athlete in order for him/her to determine the accuracy of the analysis for himself/herself. Such an approach is very important because of trust and further motivation, as well as for the formation of the relationship between the teacher/coach and the student/player and vice-versa [2, 9].

### 2.3 Witty SEM system

This measuring instrument also represents the Microgate technology and it is comprised of several (1–16) sensor indicators (size $7 \times 5$ cm$^2$). Each of the indicators is composed of a series of LEDs that have the possibility of forming specific marks in the shape of various direction indicators, numbers and letters which are then displayed in different colors. The device is managed by a program console that, in addition to some pre-programmed tests, has the option of designing custom tests that are specific for each particular sport (e.g. basketball [2, 9, 26]) (**Figure 8**).

Based on the obtained results, it is possible to assess the examinee's score in basic and situational tests for assessing agility, reaction time or coordination, as well as in evaluation processes of acquiring certain motor skills in combination with the mentioned motor abilities (e.g. ball dribbling) (**Figure 9**) [9].

### 2.4 The chronometer Witty-timer

The compact size, ergonomic shape, and innovative design make the Witty timer practical and easy to use. Graphical icons and on-screen instructions on its

**Figure 8.**
*OptoJump system. Web source: www.optojump.com.*

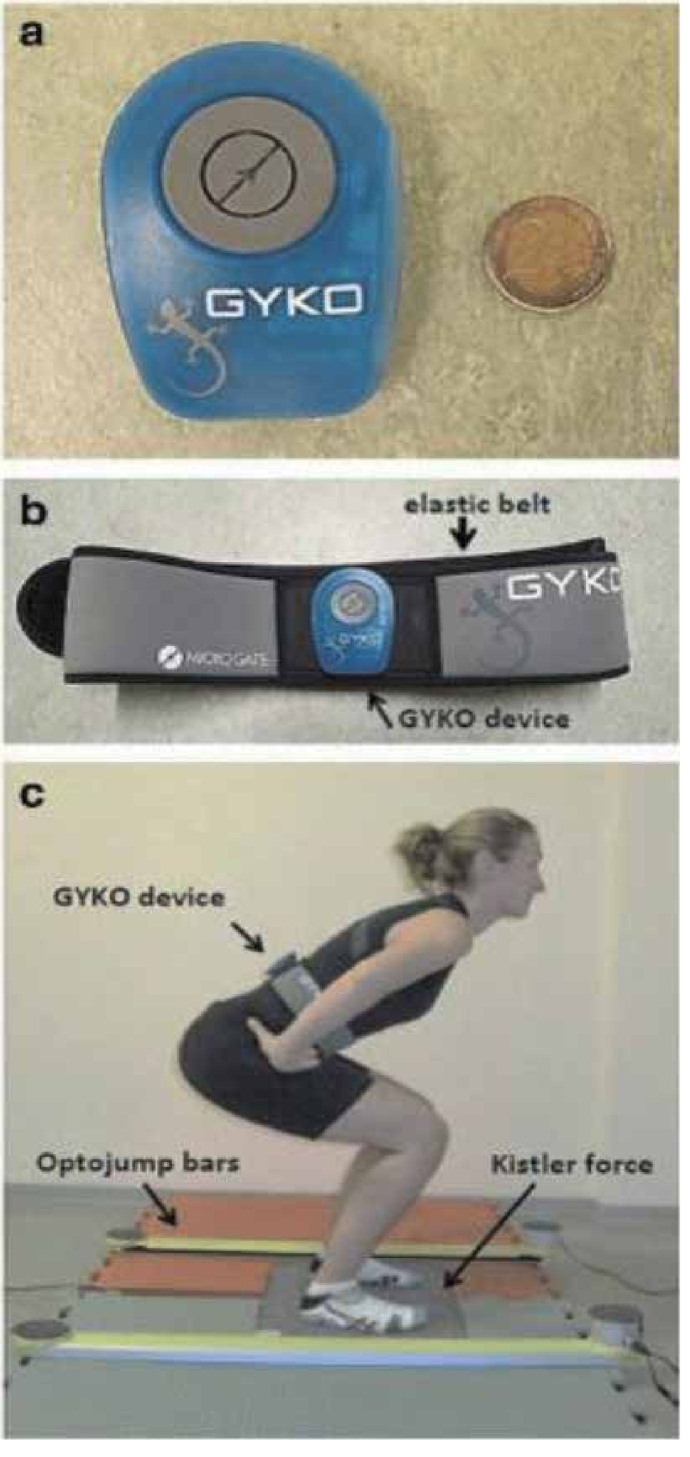


**Figure 9.**
*Gyko sensor. Web source: http://gyko.microgate.it/en. (a) GyKo inertial measurement tool for the analysis of the movement of any body segment, (b) GyKo mounted on a belt, and (c) using the Gyko device*

color display ensure user-friendliness and ease of use. With8 different radio frequencies to choose from, it is possible to work simultaneously with several Witty timing systems (timer and photocells) in the same training area. Various preconfigured test types are available (single tests, group tests, in-line tests, go and return, counter, etc.), plus the user can also create customized test protocols directly on the timer (**Figures 10** and **11**) [27].

### 2.5 Telemetric measurement of current utripa

The use of telemetric technology brings considerable advantages over the conventional method of measuring heart rate. In particular, they come into force in the games of the man. T. i. telemetry eliminates the majority of weaknesses or the deficiencies that make the measurement blink in the classic way in the mentioned sports are less useful [9]. The basic idea of the telemetric method of measuring heart rate is remote measurement.

They are only equipped with a transmitter, which, with the help of an elastic band, is attached to the chest, just like in classical measurements. A sufficiently strong receiver gives the trainer immediate feedback on the heartbeat of the athlete and allows you to monitor real-time exercise intensity. A very useful system for measuring heart rate in team sports was developed by the Swedish company Activio. It was created in cooperation with the Swedish basketball team. He also successfully used it during preparations for the 2003 EP appearance in Sweden [9].

### 2.6 Shooting critical components

In 2015, a literature review was made by Okazaki to identify the factors behind a successful jump shot. In order to do this, the authors divided the potential factors into three categories: ball trajectory, segmental movement organization and variables that influence shooting performance. Below is a summary of the authors' discussion regarding each of these categories.

**Figure 10.**
*Witty SEM system. Web source: http://www.microgate.it/Training/Witty/WittySEM.*

**Figure 11.**
*The chronometer witty timer.*

### *2.6.1 Ball trajectory*

Upon examination of ball trajectory, three components stand out as decisive for a successful shot: release angle, velocity and height (**Figures 12** and **13**).

The angle of entry of the ball into the basket is one of the most important factors for shooting success. This is due to the fact that by increasing the angle, one instantly increases the width of the basket, giving the ball a larger area to go in. There are three variables that, together, determine this angle: vertical displacement, horizontal displacement and velocity (**Figure 14**) [28].

The vertical displacement of the ball is negatively correlated with the release height and positively correlated with the release angle. In other words, the lower the release height and/or the wider the 15-release angle, the greater the vertical displacement of the ball. In simple terms, the vertical displacement of the ball may be defined as the vertical distance traveled by the ball from the moment it is released to the moment is reaches the basket. The horizontal displacement of the ball is a similar concept, but from a horizontal perspective; i.e. it represents the distance between the shooter and the basket. An increase in horizontal displacement must be accompanied by a corresponding increase in the velocity of the ball if the ball is to reach the basket [28]. The authors thus demonstrate that "these three factors (ball vertical displacement, ball horizontal displacement and velocity) are affected by release velocity, angle and height".

## 2.7 IoT in Basketball

### *2.7.1 Evo one*

Evo one is a smart basketball that is meant to give feedback to the user upon the act of shooting. When the user shoots the basketball, he will hear a beep if the ball's backspin rate is 2–3 rotations/second (the ideal rate). The purpose of this feature is to let the user know that his attempt was successful and create shot consistency

**Figure 12.**
*A powerful antenna directly connected to the computer allows measurement at a distance of up to 200 m, and the transmission and storage of data on the computer.*

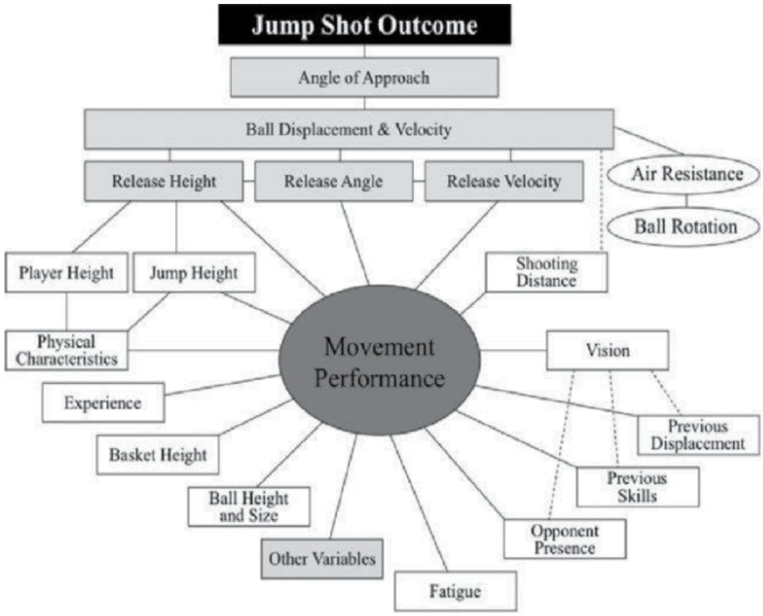


**Figure 13.**
*Variables that influence the basketball jump shot (Okazaki et al. [28]).*

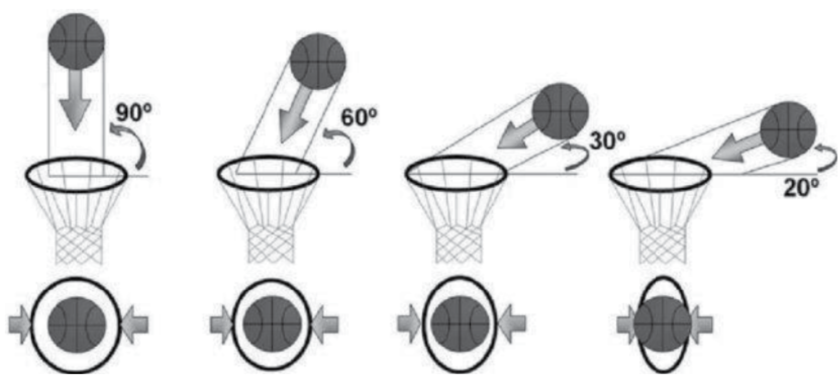


**Figure 14.**
*Virtual target of the basket rim as a function of the angle of entry of the basketball (Okazaki et al. [28]).*

through muscle memory. It measures the ball's backspin using only one sensor located inside the ball. While there are already a number of reviews on this device, the performance product review website Weartesters provides possibly the most succinct and accurate summary of its pros and cons. According to them, apart from the fact that the ball has been made according to regulation size and weight making it no different to a common basketball, the main pro identified by the consumers is its leather cover which gives the user a good grip and touch. Having said this, a leather cover makes it more of an indoor ball than an all-surface ball [29]. Regarding the cons, there are some considerable ones such as the dead spot on the ball where the sensor is inserted, which affects dribbling capacity and turns it into a simple catch and shoot ball, preventing it from being used in a game. However, for the purpose of shooting this is not a major concern. Another important issue is the inconsistency of the sound feedback. Indeed, the ball does not provide feedback unless the player's fingers are aligned with its ribs even if the shot is perfect in terms of backspin, which poses serious questions regarding the feasibility of its use in a real game situation where quick catch and shoot is fundamental and players do not have time to adjust their grip. In addition, it is unable to differentiate between a pass and a shot attempt, i.e. should the fingers be aligned, it will beep whenever it reaches the ideal backspin, even if it was a pass. Furthermore, it has been noted that the lack of consistent and accurate feedback can promote some bad habits in shooting motion (**Figure 15**) [4, 30].

The main purpose of the Wilson X smart basketball is to track field goal accuracy. It is made to regulation size and weight with a solid grip and durability, suitable for both indoor and outdoor use. The sensor is embedded within the ball and does not require charging (lasting for 100,000 shots). In addition, the product comes with a mobile app which enables the user to track his/her performance on his/her mobile phone via Bluetooth connection. However, there are some limitations. For instance, in order to ensure tracking accuracy, the ball must go through a hoop at least 10 ft. tall, with a tight net and rigid backboard, and it must hit the floor. A number of consumer reviews highlight two important issues. The first one is related to inaccurate tracking of field goal percentage and attempts. In actual fact, the ball has been reported to record some made shots as missed and vice versa, and to not acknowledge some made attempts at all. While Wilson estimates that the ball has an accuracy of 97%, the American technology news and media network-The Verge argues that it is only around 80%. This is not great news since the main purpose of the ball is to monitor field goal percentage. The second main concern is related to the synchronization between the ball and the user's mobile phone. Users have described the process as more difficult than advertised and plagued with interruptions throughout. Another criticism has to do with the fact that the app only provides a basic shot chart showing the player's accuracy rate from specific shooting ranges, but not from 27 different shot angles or locations within the same range which could be very useful especially for players who shoot better from different positions (**Figures 16** and **17**) [31].

On a more positive note, the app provides four interesting modes that will keep the user engaged while practicing. The first mode is called free range and is essentially a shoot-around game tracker that shows shooting percentage as well as distance from the hoop. The free throw mode tracks made/missed shots in real time from the free throw line. In the buzzer beater game mode, the clock keeps ticking and the player is required to repeatedly shoot under pressure as every shot made adds seconds to the clock extending the game experience. Finally, the game time

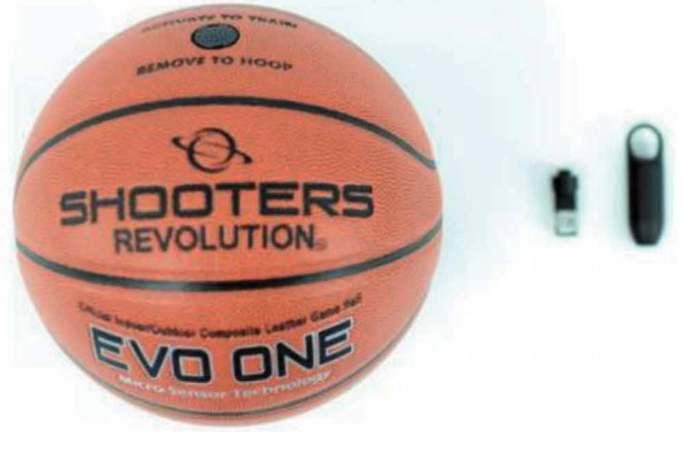


**Figure 15.**
*Wilson X. Web source: https://evo1sports.com/product/evo-one-sensorized-basketball/.*


**Figure 16.**
*Wilson X smart basketball. Web source: https://evo1sports.com/product/evo-one-sensorized-basketball/.*


**Figure 17.**
*Wilson X application modes. Web source: https://www.prodirectbasketball.com/responsive/pro-ditect/wilson-x-connected.aspx.*

mode recreates a real game environment including actual crowd sounds and commentary. It tracks both field goal percentage and points, and lets the player know whether his/her effort was sufficient to secure the victory [29].

Although these game modes attempt to make the user more familiar with playing under pressure, without another actual player guarding and blocking the user in real life, their help in improving game performance remains limited.

### 2.8 94fifty

The 94fifty smart basketball enables the user to check his/her shot arc, rotation and release speed. It is a ruggedized ball of regulation size and weight, with a good grip suitable for both indoor and outdoor use. It does have a dead spot that can be found while dribbling but, as for Evo 1, this is not a major concern for shooting practice alone. While, at first, the ball was unable to track made or missed shots, with the increment of the smart net, this function has now been made possible. Furthermore, unlike the previous basketballs, this one can be charged wirelessly and has approximately 8 hours of battery life with continuous use. Following performance analysis of some of the best basketball shooters, the developers concluded the optimal range for shot arc to be between 42 and 48 degrees, ideal backspin between 130 and 150 rotations per minute and best release speed under 0.7 seconds, and they calibrated the ball accordingly. When shot, the ball provides instant feedback regarding what is being measured. Thus, if it is arc, there will be positive feedback if the player's shot arc falls within the optimal range, and an alert message if not. In addition, the app offers a wide variety of drills designed to improve performance in specific categories, such as dribbling and shooting. In the latter category, on which this report focuses, there are various drills available with different levels of difficulty - from playground all the way to professional, and there can be combinations of shot accuracy with shot arc, release speed or shot rotation.

However, there are limitations to what the ball can measure at any given moment. For instance, the ball can only measure and display one indicator at a time and is not equipped with certain useful tools such as GPS for determining shooting location. Hence, before performing a shooting drill, the player needs to select what indicator to measure, identify his/her shooting location and whether it is a free throw or not (e.g. jump shot). Nonetheless, overall the range of workouts offered by the app does facilitate skill improvement and player engagement (**Figure 18**) [32, 33].

In studies that were carried out to assess the reliability of the 94fifty, it was concluded that it is not only possible to use it for practical purposes but also for scientific reasons given the accuracy of the obtained results. It was also considered an important instrument for the overall improvement of the basketball training process since this device allows the user to receive valuable feedback [34].

*2.8.1 ShotTracker*

ShotTracker is a shooting tracking system that registers missed and made shot attempts. For it to work, the user has to have a wrist sensor that captures shot


**Figure 18.**
*94fifty gear. Web source: https://test-94fifty.myshopify.com/products/two-ball-pack.*

attempts and a net sensor that registers whether or not the ball went in. Since there is no need for basketball sensors or smart balls, the player can choose his/her basketball of preference, which is an advantage as smart basketballs have been criticized for having different grips and not always having the touch of a regular ball. However, the fact that the net sensor has to be attached to the net which typically is 10 ft. above the ground may become a major inconvenience, especially in public places, since a ladder would be needed to reach the net and attach the sensor. Furthermore, if there are multiple players shooting at the hoop with the net sensor, all the shots will be taken into account, and this presents a problem for measuring individual performance [29].

Nevertheless, ShotTracker remains user friendly in other ways, coming with a wrist band, a sleeve and even a shirt giving the user different options to correctly wear the sensor. In addition, both sensors can be charged at the same time and are weather proof. With this equipment, the user is able to track his/her field goal percentage and shooting location (**Figure 19**) [29].

In addition, the app enables the user to look at his/her results in real time and assess progress over time by checking personal daily, weekly and monthly stats. Another great advantage of the app is that coaches can monitor the players' results and, based on the feedback from the drills, identify areas of weakness and customize workouts to the needs of each player [35].

### *2.8.2 Hoop tracker*

The Hoop Tracker is a basketball shot tracking smartwatch which provides real time feedback on the player's shot attempts. It detects shooting location at all times and whether the shot was made or missed (**Figure 20**).

In order to do this, only two pieces of equipment are required: a wireless shot detector and a smartwatch. The shot detector is held in place by a powerful magnet designed to not impact the outcome of the shot which is a key feature. It also comes with a mounting pole which enables the user to place it on the rim safely from the ground, giving it an advantage over the Shot Tracker. The wristwatch, although lightweight and intended to be worn on the non-shooting hand to minimize the chance of damage and obstruction to the shot, is still an accessory that is not used in a game situation and, therefore, not ideal from this perspective. However, it can be


**Figure 19.**
*ShotTracker gear. Web source: https://shottracker.com/.*

**Figure 20.**
*Hoop tracker gear. Web source: https://shottracker.com/.*

quite useful as real time results are only a quick glance away during workout. When the ball goes through the hoop, it activates the sensor, which subsequently sends a signal to the watch that the shot was made. When a shot is missed, the vibration created by hitting the backboard or the rim is detected by the accelerometer sensors which send a signal to the watch that the shot was missed. Moreover, the developers incorporated a delay in the signal to account for the shots that bounce around the rim before going in. The only shot it cannot automatically detect is the air ball, for which there is a button on the watch that can be pressed to record it as a miss. With access to shooting percentages from different locations, players can evaluate their success rate from different positions on the court e.g. free throws, three-pointers, etc. and take advantage of the training modes available for those positions. Once their data is uploaded, they can access the Hoop Tracker dashboard on their own computer and analyze their stats, track their long-term progress and identify their strengths and areas for improvement. There is also a coach mode which allows coaches to monitor their players' progress and customize training accordingly (**Figure 21**) [36].

The software also comes with some fun games that will keep the player engaged while improving his/her skills, such as the 3 pt. challenge, the all FG mode or the 100 pt. challenge [37]. All in all, they have tried to appeal to both professional players and coaches with regard to training modes and stats, and to amateur lovers of the game by offering fun games and even a calorie counter.

### *2.8.3 Catapult*

Catapult's ClearSky T6 is a tracking system unlike any other. It combines inertial data sensors with RF ultra-wideband tracking systems to determine the athlete's


**Figure 21.**
*Hoop tracker features. Web source: http://www.hooptracker.com/.*

exact location, whether indoors or outdoors, without needing satellite reception tools like GPS which may be unreliable inside some modern sports facilities. It uses triangulation between anchors that can be set up relatively quickly throughout an arena or stadium to continually ping the devices for real time location information. A recent study confirmed that its calculation of position, distance and average speed from the local positioning system shows a low level of error, with an average difference in distance lower than 2%, which validates the use of this technology for indoor analysis of team sports. Nonetheless, it was concluded that the placement of anchor nodes and field of play in relation to the walls of the building has great influence on the location positioning system output [38]. Catapult technology does not only capture the location, but it also measures PlayerLoad—a one number validated metric that shows work rate, and even health indicators like heart rate. Developed with the Australian Institute of Sport, PlayerLoad summarizes all the data points provided by micro movements into one understandable number and is measured instantaneously approximately 100 times per second. This metric takes into account the acceleration made in all possible directions, front, sideways and upwards. Distance-based measures can lead to errors of judgment, for instance, in basketball all players attack and defend so while the distance covered may be the same, the number of jumps, rotations and contacts is misrepresented. An acceleration-based metric, such as PlayerLoad, indicates the mechanical load on muscles and joints.

In the 2014–2015 season, the Golden State Warriors used catapult technology during practice (NBA has not allowed the use of inertial sensors in the actual game) to help monitor the players' work load and optimize its management. The outcome speaks for itself as the Warriors finished regular season with the least amount of time lost to injury in the league. The challenge going forward relies on 32 understanding the correlation between workload and injury patterns. By identifying the thresholds, greater knowledge is achieved regarding the players' tolerance level, and coaching staff may prevent players from leaving their optimal loading zone. The same can be applied to performance; patterns may be identified regarding workload and performance, enabling staff to know at what load levels the athlete will perform best. In summary, catapult provides new data which can be transformed into information if adjusted data mining techniques are applied, and consequently generate knowledge from the findings (**Figure 22**) [39].

### *2.8.4 Noahlytics*

Noahlytics is a shooting tracking system that tracks players' shots from anywhere in a basketball court. It measures the location from where the shot was taken whether the shot was made or missed, entry angle, depth and left-right position of the ball when reaching the hoop and provides real time feedback. It has the ability


**Figure 22.**
*Catapult's ClearSky T6. Web source: https://www.catapultsports.com/products/clearsky-t6.*

to capture the position of the ball 30 times per second, ensuring that the trajectory and position of the ball when reaching the hoop is precisely recorded. Users can find information about their shots in a cloud-based platform in real time and are able to

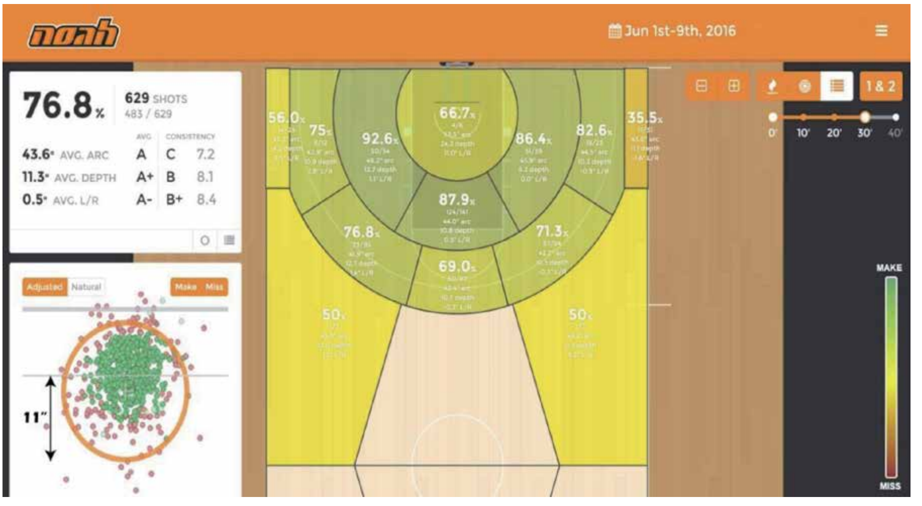


**Figure 23.**
*Noahlytics entry attributes. Web source: https://www.noahbasketball.com/blog/noah-basketball-launches-new-noahlytics-data-service.*

| Current | Evo1 | Wilson X | 94fifty | ShotTracker—individual | Hoop tracker | Noahlytics | Catapult |
|---|---|---|---|---|---|---|---|
| Smart ball | Ball rotation | Made or miss (requires net), shot location | Release speed, shot arc, ball rotation | | | | |
| Net sensor | | | Made or miss | Made or miss | | | |
| Wrist sensor | | | | Shot attempt | | | |
| Hoop sensor | | | | | Made or miss | | |
| Smart watch | | | | | Shot attempt, shot location, made or miss | | |
| Backboard sensor | | | | | | Entry angle, shot depth, left-right position, made or miss, shot location | |
| ClearSky T6 | | | | | | | Heart rate, PlayerLoad |

*Web source: https://www.noahbasketball.com/blog/noah-basketball-launches-new-noahlytics-data-service.*

**Table 1.**
*Metrics measured by current devices.*

filter data by different variables like court placement, player name or even made or missed shot, for example (**Figure 23**).

Noahlytics was the system used to record the ball entry attributes of over 1 million shots in Marty and Lucey's winning research paper. Based on the conclusions of the study, its potential is undeniable as registered data contributed to greater understanding of the factors behind the success of a basketball shot. For this reason, Noah Basketball won the 2017 Startup Competition in its category at the Sloan Sports Analytics Conference [40].

By way of summary, a compilation of the metrics that are captured by each device is shown in **Table 1**.

## 3. Conclusion

In this humble chapter we tried to analyze the application of game basketball patterns through sports technology. In which we have presented some of the latest equipment, technology tools and which serve to increase the performance of basketball game. In the end we can conclude that in this chapter will be considered the application of basketball game models through sports technology the last time is very important in raising the performance of basketball players. Based on many years of experience as a player, trainer, a good connoisseur of theory and scientific-experimental practice, basketball pedagogue, as well as the use of contemporary professional and scientific literature for this chapter, it is very well seen that the application of game models of basketball through sports technology is important for the basketball game.

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Chapter 8

# Sports and Health as Cornerstones of Tourism Development: Case Study of Montenegro

*Anđela Jakšić-Stojanović and Neven Šerić*

## Abstract

The modern phenomenon of tourism is more focused on specific forms of tourism in which sports and health tourism play a very important role. That fact is not surprising having in mind that they represent interconnected activities that complement each other and give each other completely new dimension. On one side, sports and health represent very important content of tourist offer because of the fact they enable tourists to become active participants in various activities, and on the other side, they represent important driving force for visiting particular destination. The idea of this chapter is to provide a theoretical and practical framework of this issue with a special focus on case study of Montenegro. According to the results of the research that was carried out, the general conclusion is that Montenegro has extremely valuable natural resources and potentials for the development of sports and health tourism, but there are still a lot of challenges that should be faced in the future in order to improve the quality of tourist offer and the level of tourists' satisfaction as well as to create completely new image of the destination and position it as high-quality sports and health tourist destination on international market.

**Keywords:** tourism, sport, health, destination, Montenegro

## 1. Introduction

Sports and health tourism represent some of the fastest-growing segments in tourism industry, and their popularity has been significantly increased. That is the main reason why these two phenomena attract attention of many authors especially in the last decades [1–4]. Since ancient times, sports and health have been a very important driving force and motif for visiting particular destination [5]. Today, it seems more than ever before that they represent very important content of tourist offer in which tourists become active participants in realization of many activities such as hiking and biking, water sports, tennis, golf, skiing, riding, sports games, extreme sports activities, wellness and spa, etc.

The expansion of these two types of tourism is completely expected having on mind many factors—significant demographic changes, the increasing share of the elderly population, prolonged life expectancy of the population, habits and interests of a baby-boom generation, as well as some other factors such as stress, the lack of free time, unhealthy lifestyles, the usage of modern technologies, pollution, etc. In that sense, it is clear why health and sports tourism play an important role in revitalization of the psychophysical abilities of people. Trends and perspectives on international tourist market go in the same direction, so in the future it is expected to have a significant growth of nature tourism combined with sporting activities, health-recreational tourism, golf tourism, wellness tourism, as well as activities such as fitness, mountain hiking, mountain biking, hiking and biking, etc. [6, 7]. Rafting and kayaking as well as extreme sports are also expected to expand.

It is important to mention the fact that sports and tourism in the last decades succeeded to create a variety of different forms which attract a large number of different target groups, so it is not unexpected that a large variety of mutual interest from the management point of view appeared [8, 9]. That convergence of mutual interests represents very powerful tool in the process of creating a high-quality whole-year destination with diversified offer and competitive advantages on international tourist market.

## 2. Methods

The analysis of development of sports and health tourism in Montenegro started from the SWOT analysis which actually represents the process of identification of main strengths, weaknesses, opportunities, and threats [10]. The aim of this analysis was to identify the main internal strengths and weaknesses of Montenegro, as well as external opportunities and threats that may have an influence on its future development as sports and health tourist destination.

Except SWOT analysis, survey among the tourists was carried out as well. The first phase was the preparation of structured questionnaire in order to address the needs of this paper. The questionnaire contains a total of 14 questions. The first part relates to biological, social, and economic characteristics of respondents, while the second part contains questions that relate to the subject of the research itself. The questionnaire contains open-ended questions in which respondents independently present their opinions and attitudes, closed questions in which respondents choose one of the offered answers, as well as the so-called pivot questions in which respondents rank responses according to their significance. The questionnaires were prepared in English, Russian, Albanian, and Montenegrin/Serbian/Croatian/Bosnian language.

The second phase was conducting a survey which was realized from June to September 2018. Ten interviewers were included in the realization of this task, and they were thoroughly familiar with the method of interviewing the tourists. One hundred and forty respondents were personally interviewed in 12 Montenegrin municipalities. Respondents were both domestic and foreign tourists. They were selected by random sample method, and the sample was stratified.

The third phase was statistical analysis of the results of the survey with a special accent on data which refer on motivation, preferences, and attitudes of tourists, as well as the level of their satisfaction with quality of tourist offer.

The analyses of the results of the survey and their appropriate interpretation led to preliminary conclusions related to positioning Montenegro as sports and health tourism destination. These conclusions are strongly supported by data which refer to trends and perspectives on international tourism market in order to create a theoretical and practical framework for the creation of strategy of sports and health tourism in Montenegro.

## 3. Results and discussion

The analysis of development of sports tourism in Montenegro is presented in **Table 1**.

| Strengths | Weaknesses |
|---|---|
| • Natural beauties (sea, mountains, national parks, rivers, lakes, etc.)<br>• Extremely valuable natural resources—sand, mug, mineral waters, thermal sources, etc.<br>• Climate conditions<br>• The richness of contrasts<br>• Closeness to large emitting markets<br>• State of ecological country<br>• Competitive prices<br>• Growing number of 4- and 5-star hotels with high-quality wellness and spa and sports infrastructure<br>• The investments and the improvement of infrastructure | • Lack of clear vision, mission, clear strategic goals and measures, and activities that should be carried out in the future<br>• Mostly underdeveloped infrastructure<br>• Nonintegrated tourism product<br>• Lack of integration in terms of policy, research, and education<br>• Lack of promotion on national and international levels<br>• Lack of service quality control<br>• Insufficient power of clusters, associations, and societies in the field of sports and health tourism<br>• Low level of cooperation between different stakeholders |
| **Opportunities** | **Threats** |
| • Anticipated growth rate of tourism industry<br>• Prediction of UNWTO as well as positive trends and perspectives in tourism and hospitality industry in Montenegro<br>• International recognition of Montenegro as a tourist destination<br>• Diversification of consumer segments and sports and health tourism products<br>• Anticipated growth rate of sports and health tourism<br>• The increasing share of elderly population<br>• Trends for more healthy and active ways of life<br>• Stress, lack of free time<br>• Baby-boomer generation<br>• Raising awareness of people regarding the need to preserve health<br>• The process of EU integrations | • Instability of the region<br>• Climate changes<br>• Increasing number of competitive destinations in the field of sports and health tourism<br>• The rapid development of technology that imposes the need of continuous investment and improvement of quality of tourist offer |

**Table 1.**
*SWOT analysis of Montenegro as sports and health tourism destination.*

By analyzing the main strengths, weaknesses, opportunities, and threats of Montenegro as sports tourism destination, as well as opinions, expectations, beliefs, and attitudes of tourists, it may be concluded that natural resources such as sea, mountains, national parks, beautiful landscapes, lakes, rivers, etc. as well as a very favorable climate and geographical position in relation to large European centers represent a great base for future development of sports tourism. Except that, it should mention that a clear commitment of country to reach the European market, huge projects in tourism, a growing number of 4- and 5-star hotels with wellness, spa, and sports facilities, recent investment in infrastructure, etc. make Montenegro a serious candidate for regional, if not a European, destination of sports tourism. In combination with trends and perspectives on global market such as anticipated growth of sports tourism, trends for healthy active ways of life, raising awareness about the importance of health for quality of life, etc., this potential becomes even bigger.

But, on the other side, it is not difficult to conclude that there are many weaknesses of the destination itself such as underdeveloped infrastructure, lack of integral strategic approach, insufficiently integrated tourist products, lack of promotion on international and national levels, etc. which may seriously slow down the future development of Montenegrin tourism if there is no strategic plan for their overcoming. This is extremely important having in mind the fact that the increasing number of competitive destinations in the field of sports and health tourism as well as rapid development of technologies imposes the need of continuous investment and improvement of quality of tourist offer.

The results of the SWOT analyses were strongly supported by the results of the survey in which 140 respondents participated. Out of the total number of respondents, 52% are female and 48% were male. About 25% of the total number of respondents are domestic tourists and 75% are foreign tourists (25% were tourists from the neighboring countries—Serbia, Bosnia and Herzegovina, Croatia, Slovenia, Macedonia, and Albania—while 50% were tourists from other countries). When it comes to age structure of guests, the highest number of tourists 26% was between 20 and 29, 26% between 30 and 39 years, 19% between 40 and 49, 15% between 50 and 59, 7% of tourists between 15 and 19, and 7% has 60 or more years.

Most tourists have a high school diploma (40%) or college (40%), 18% have a higher school diploma, 1% has only completed elementary school, and 1% has unfinished elementary school. When it comes to monthly income, the research indicates that 46% of respondents have average monthly incomes, 20% have incomes above the average of their country, 8% are significantly above the average, while 15% have incomes below the average of their country, and 11% were found to be significantly below the country's average. This is completely in accordance with trends and perspectives on the global market—according to some authors, the majority of tourists in the future will actually be tourists with some average monthly incomes [11].

The results of the research showed that tourists in Montenegro usually reside 7 (40%) or 10 days (26%) and 24% of tourists in Montenegro stay up to 5 days, while 10% of tourist stay more than 10 days. Trend for shorter, but more frequent breaks is evident. Most of the tourists (55%) spend between 250 and 500 euros per person (accommodation and travel costs excluded), 12% between 500 and 1000 euros per person, and 8% over 1000 *euros*, while 25% spend less than 250 euros per person during holiday. These data are also completely in accordance with trends and perspectives on global tourist market in which consumption in tourist destination is continuously increasing [12]. For most of the tourists, Montenegro has completely fulfilled their expectations (58%), and the percentage of those for whom Montenegro exceeded expectations is also very high—22%. For 20% of respondents, Montenegro only partially reached the expectations or did not reach them at all. The most important results of the survey are presented in **Table 2**.

The results of the research clearly show that although the slogan "wild beauty" is clear, effective, and attractive, it does not present the main competitive advantage of Montenegro such as the richness of contrasts, natural beauties, the state of ecological country, and the short distance from the sea to the mountains. Not only the verbal but also the visual elements of the logo do not represent the uniqueness of the destination itself.

It is clear that it is necessary to do rebranding of a destination itself including its logo and slogan which should be based on its main competitive advantages which make the destination unique, different, special, and superior to the main competitors [13]. In that sense, previous logo of Montenegro as tourist destination seems to be more appropriate because of the fact that it includes important elements of tourist offer of Montenegro such as nature, sea, weather, etc. even in its visual part. The fact that this logo was strongly supported by marketing tools which perfectly

| **Associations with slogan "wild beauty"** | | **Tourists' perception of the seasonality of tourist offer** | |
|---|---|---|---|
| 63% | Wilderness | 65% | Montenegro is perceived as a summer destination |
| 26% | Natural beauties | 25% | Montenegro is perceived as a winter destination |
| 6% | Richness of contrasts | 10% | Montenegro is perceived as a whole-year destination |
| 5% | Other | | |
| **Key disadvantages of future development of Montenegrin tourism** | | **The main motives for visiting Montenegro** | |
| 42% | Pool infrastructure | 40% | Natural beauties |
| 18% | Noise, crowding, and dirtiness | 13% | Experiences and events |
| 14% | Lack of strategic planning | 13% | Active holiday and sports activities |
| 12% | Lack of promotion | 12% | National parks |
| 10% | High prices | 7% | Gastronomy |
| 4% | Other | 7% | State of ecological country |
| | | 5% | Health reasons |
| | | 3% | Other |
| **The frequency of practicing sports activities during vacations** | | **Tourists' satisfaction with sports and health tourism offered in Montenegro** | |
| 78% | Regularly practiced (swimming, hiking, biking, rafting, etc.) | 55% | Generally satisfied |
| 15% | Rarely practiced | 10% | Highly satisfied |
| 7% | Do not practice any kind of activity at all | 15% | Quite satisfied |
| | | 13% | Not satisfied |
| | | 7% | Not satisfied at all |

**Table 2.**
*The most important results of the survey.*

identified all competitive advantages of Montenegro as tourist destination such as state of ecological country, richness of contrasts, biodiversity, gastronomy, the hospitality of local people, etc. is an additional proof for this statement.

The fact is that tourists identified very clearly the main disadvantages of the destination itself such as poor infrastructure, noise, crowding and dirtiness, the lack of strategic planning, lack of promotion, etc. It is important to mention that there are already some activities that are carried out at national level regarding the mentioned weaknesses. One of the most important ones is the construction of the first highway in Montenegro whose construction began in 2015, and it includes four phases in order to connect better south, central, and north part of the country as well as Montenegro with neighboring countries. The first phase that connects the capital city and north part and that includes the construction of 42 tunnels and 92 bridges is expected to be finished in 2020. After the realization of this project, the biggest one since the country's independence, the traffic infrastructure will be significantly improved which will lead to the improvement of the quality of tourist offer as well. Regarding the strategic planning, it is necessary to mention that the set of strategic acts has been already adopted by the government, but there are some problems regarding their implementation which are mainly caused by insufficiently clear roles and responsibilities and lack of cooperation between different stakeholders—on national, regional, and local levels as well. One interesting issue that is recognized by the tourists is lack of promotion at all levels, and this is definitely one of the problems that should be paid great attention in the future. Although the strategic marketing plan for period 2018–2020 has been adopted, most of the proposed measures and activities are still not realized. It is also necessary to adopt the strategy of digital marketing having on mind the role of digital media in the era of globalization, internationalization, and modernization of business. In that sense, the focus should be put on online promotion (redesign of web presentations, preparation of online brochures, promotion of offer on social networks and platform, storytelling, interactive infographics, virtual reality, etc.), digital management—customer relationships (study visits, data basis, loyalty programs etc.)—promotion of digitalization, and online promotion on national level (promotion of online payment, training of representatives of tourism and hospitality industry regarding online marketing, raising awareness of local people about benefits of development of tourism and hospitality industry, and the importance of their active participation, etc.). Except this strategy, strategy of sports and health tourism in Montenegro should be prepared and adopted as well. Its preparation and implementation should be based on the strong cooperation between tourism and sports and health industry as well as on integration in terms of policy, research, and education, which will represent the cornerstone for future development of these kinds of tourism in Montenegro.

Although holiday on the seaside which is mostly perceived as "passive holiday" (3S: sea, sun, sand) still represents the main motif of visit to Montenegro (65%), its significance is much lower than before. This means that it is necessary to introduce, develop, and promote new tourist products and services which will attract tourist to visit the destination not only during the summer season [14]. Special attention should be definitely paid on sports and health tourism, having on mind the potential of Montenegro for their development, trends, and perspectives on international tourist market as well as the fact that these specific types of tourism may significantly contribute to solving of problem of seasonality [15].

During making choice of Montenegro as holiday destination, motives connected with "active" holidays play more importantly than ever before such as experiences and events, natural beauties, active holiday and sports activities, gastronomy, health reasons, national parks, state of ecological country, etc. This fact should be used in marketing campaign and presented by different promotion tools in order to attract new target groups and position Montenegro as a destination which provides a lot of possibilities for beautiful active holidays full of adventures, unforgettable experiences, etc.

It is also interesting to mention the fact that most of the tourists regularly practice some kind of sport activities such as swimming, hiking, biking, rafting, etc. during their vacation in Montenegro. The activities which are the most popular among the tourists are swimming and water sports, cycling, hiking and biking, skiing and winter sports, rafting, etc., which implies that these activities should be included in all segments of tourist offer.

Although the results of the survey have shown that tourists are generally satisfied with the quality of sports and health tourism offered in Montenegro, it seems that this potential is still not appropriately and completely valorized and that there is a still a lot of space for future improvement. In that sense, it is necessary to create main centers for sports and health tourism which will be the main spots which will attract this kind of tourists. According to some authors [16, 17], special accent should be put on:

- Ulcinj should be given priority in the future having in mind the richness of natural factors for the development of health tourism such as Mediterranean-Adriatic climate, mineral water sources, sea salt, wellness of sand, and rich plant ecosystems. It is important to mention that in 1992 by the order of the Kingdom of Yugoslavia, Ulcinj was declared as a "Spa and Climate Health Resort." The sea temperature makes the optimal bathing possibilities in the seawater about 6 months, from May to October. The water clarity in the summer is as much as 38 m, and on the sea in front of Ulcinj the highest water transparency in the Adriatic Sea is measured at 56 m. The long healing factors are sand on the beaches, which is very clean, with unusually fine small particles; there is not even the slightest admixture of soil, sludge, organic materials, etc. According to the chemical composition of Ulcinj sand, there are about 30 mineral substances that are biologically very active. It contains mild radioactivity which makes it very suitable for medical applications, especially in the case of diseases of the organs of movement and spine, rheumatism, desmopathy, sciatica, as well as conditions after injuries to these organs. The sulfur water that springs along the sea on the "female" beach has "miraculous" medicinal properties, and according to legends and stories, it has beneficial effects especially for women who do not have children. By mineral composition, the water is thus very rich. Mineral mud extends around the basin of the Ulcinj saltpan, about 2 km from the sea. Scientific tests of this mud confirm that it has one of the best qualities on the Adriatic. Untreated seaweed from the sea saltwater pool in Ulcinj has a "concentrated sea" effect, which is suitable for the treatment of rheumatism and diseases of the organs for movement. All these natural factors can rarely be found in one place, thus making this a unique place.

- Igalo is a place which should be valorized as a center of modern therapy, thalassotherapy, rehabilitation, prevention, and recreation. In order to reach this, it is necessary to undertake some measures such as modernization of existing centers and creation of new ones, providing additional values for consumers of services, modernization of traffic and communal infrastructure, realization of promotional activities focused on specific target groups, etc. Near the mouth of the Sutorina River to the sea, along the sea shore, there are several sources of mineral water, four of which are located. These mineral waters are based on chloride and muriatic, and according to the German classification, this mineral water belongs to the group of sodium chloride waters. It can be used in the treatment of various diseases, such as hypoacidities, dyskinesia, gallbladder disease, chronic constipation, and slow peristalsis. It is also used in the form of aerosols in respiratory tract diseases. Thanks to the healing sea mud, Igalo has developed into the largest centers in former Yugoslavia and one of the largest in Europe. This mud has pronounced hypersensitive, respiratory, and analgesic effects and is used in the treatment of many diseases, primarily those related to rheumatism.

- Prčanj in which there is already a center for the rehabilitation of children with asthmatic diseases should be further valorized in this direction. In order to reach this, it should provide additional capacities, modernize the existing ones, provide more diversified services, etc. It should definitely include Vrmac in order to reach the combination of medical and recreational contents on the route between sea and the mountains which would give this center a completely new quality.

- Risan, which is already affirmed as a classical health resort, needs to be modernized and further specialized in order to attract a larger number of different target groups.

- Tivat should also be considered as a new health center given the fact that sites Solila and Bigova, as well as the assumptions about the existence of mineral water, are present, etc.

Having on mind that all these places are situated at the seaside, they provide perfect conditions for practicing different sports activities such as swimming, water sports, tennis, golf, sports games, extreme sports activities, etc. The additional investment in infrastructure especially sports facilities would significantly improve the quality of tourist offer and the level of satisfaction of tourists.

Except in the coastal area, health and recreation centers should be developed in the continental and the mountainous parts of Montenegro, for example, on Orjen and Lovcen, as well as in lower altitude zones of Durmitor, Bjelasica, Komovi, and Prokletije. Having on mind natural beauties in this part of Montenegro which includes high mountains; national parks Durmitor, Lake Skadar, Lovćen, Biogradska Gora, and Prokletije and many parks of nature, beautiful forests, and lakes; deep and wild mountain rivers, among which the most famous one is Tara, "the tear of Europe" with the longest canyon in Europe and the second longest in the world; and Biogradska Gora, one of the three virgin forests in Europe, etc., it is clear that all these places provide a lot of opportunities for different kinds of sports activities such as hiking and biking, extreme sports, rafting, kayaking, etc.

It is also important to mention the fact that except for the already mentioned centers, the quality of other capacities in Montenegro should be further improved by the introduction of different programs such as wellness; spa; recreation programs such as massages, saunas, fitness, and yoga; weight loss programs; etc. In that sense, building fitness wellness centers is no longer a factor of comparative advantage, but a necessary prerequisite for competitiveness on the market and the key factor for the extension of the tourist season itself [18].

## 4. Conclusion

The aim of this study was to identify the main internal strengths and weaknesses of Montenegro, as well as external opportunities and threats that may have influence of its future development as sports and health tourist destination. The analyses of the results of the survey and their appropriate interpretation in combination with analysis of trends and perspectives on international tourism market led to preliminary conclusions related to positioning of Montenegro as sports and health tourism destination.

The general conclusion is that Montenegro has extremely valuable natural resources and potentials for development of sports and health tourism, as well as that all trends and perspectives on international tourism market will lead to the expansion of these types of tourism in the future. But, it also may be concluded that although natural resources are very important for development of sports and health tourism, they are neither sufficient nor the only resource of its future development—there is still a lot of work that should be done in the future from many different points of view. Because of that, it should work very intensively on continuous improvement of quality of these types of tourism and their promotion which could contribute not only to solving many problems of the destination such as seasonality, distribution of tourists regarding place and time, tourism overcome, etc. but to its better positioning as high-quality sports and health tourism destination on international market as well.

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In this era of sedentary lifestyles and disruption, sports science can propose solutions to human health matters. There is no doubt about the positive impact of sports on the physical as well as mental health of an individual, by extrapolation to the society at large. But with the advent of the latest technologies in the sports domain, the body of knowledge about sports science and human health is reaching new heights. The "*Sports Science and Human Health - Different Approaches*" book aims to expose worldwide research and development works in an explicit manner. Readers will appreciate the diversity of the topics, ranging from the use of machine learning in sports science to the psychological impact of sports and sports for peace initiatives. A large section is dedicated to wearable devices like biomechanical devices to gauge motor skills, and other smart devices to assess player performance. Beyond awareness, the multidisciplinary nature of this book is a source of inspiration for the scientific community.

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