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The Use of Technology in Sport

Emerging Challenges

Edited by Daniel Almeida Marinho and Henrique Pereira Neiva

THE USE OF TECHNOLOGY IN SPORT – EMERGING CHALLENGES

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Notice

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Meet the editors

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Preface

The development and implementation of new technology devices to help professionals, athletes, and non-athletes improve their physical fitness, performance, health, and well-being have emerged in the last few years. In fact, there has been a rapid increase in assessment instruments, which are commercially available to researchers, practitioners, and consumers, leading to a widespread of misleading concepts and technologies. Besides monitoring physical activity, it is also important to know and understand the wide range of valid measurement instruments and data that can be provided. The correct application, analysis, and interpretation of these data would benefit researchers, sports professionals, athletes, and non-athletes to improve their performance, physical fitness, health-related variables, and well-being.

This book provides the reader with a comprehensive overview of the current state of the art in technology applied to competitive and non-competitive sports, providing examples, literature syntheses, and recent applications to sports, focused on the most important evidenced-based developments under this scope. It was our intention to alert those interested in sports technology to some of the problems that development and technological progress brings us when applied to sport, as well as stimulate the intellects of all sports-related people.

The book is divided into three sections, starting with a brief contextualization of the problematic and major challenges of technology in sport. In Chapter 1, the authors briefly focus on the use of technology for improved performance in competitive sport, the role of technology in the new era of organizations, and the emerging investment that could be promoted regarding innovations in technology applied to physical activity and sport competitions.

In the second part of the book, the aim is to focus on emerging problems regarding the development of technology and its use in sport. For that, Chapter 2 synthesizes and reviews the development of high-performance facilities, modern equipment, and technology applied to physical fitness, training, nutrition, medicine, and psychology. This chapter also approaches the problem of using technology for enhancing mass participation in sport, providing several suggestions to enjoy new technologies. Chapter 3 examines the benefits of recent developments in technology that would allow coaches to improve their activity, keeping the participants engaged and focused on their goals. In this chapter the authors also analyze the technological advances in other contexts such as medicine and how this could be used in the sports industry, bridging the gap between different areas of knowledge. The last chapter of this section, Chapter 4, looks at how technology is able to help translate improved sport performance into enhanced business performance. For instance, the tracking systems in some competitive sports, such as football, are now systematically used, and this chapter focuses

on the issues around big data, security issues, and knowledge sharing to positively develop sportive and business performance.

The third section of the book includes a chapter, Chapter 5, that provides an example of new software developed to analyze signal processing data management methods to efficiently evaluate the mechanical response of a subject. This software improves the efficiency and effectiveness of the stiffness of plantar flexor muscle-tendon unit analysis as an example of technological development applied to evaluation and analysis in sport.

The wide range of issues presented in this book can be addressed to academic researchers, coaches, athletes, and also to elements of sports organizations, business administration, computer science and information systems, commercial brands, and all those interested in technology development and sport. This book is the result of many collaborating parties that we gratefully acknowledge.

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Section 1

Contextualization

Chapter 1

Introductory Chapter: The Challenges of Technology in Sports

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Henrique Pereira Neiva

Additional information is available at the end of the chapter

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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 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. This rapid increase and development not only lead to the emergence of new ways of monitoring the training and competition, to optimize performance, but also new ways of structuring sports organizations (clubs, federations, etc.) and a potential for trade until a very short time ago.

2. Technology and performance

There is a growing trend to monitor human physiological response and performance during real-time physical activities. The development of wearable technology, such as pedometers, heart rate monitors and accelerometers and their incorporation into personal devices, such as mobile phones, allows low cost and easily available monitoring systems for consumers. Besides this use by the "common person," there is a growing niche for the use and development of sensors in competitive sport environment. This will allow individual and sports teams to monitor movement, physiologically and biomechanically, to measure workload and

real-time response, trying to maximize the performance. Moreover, this will potentially allow the identification of fatigue, movement errors and perhaps prevent injuries.

Despite technology is spread everywhere in sports, the main part is the one related with athletes and their performance. Having technology just does not guarantee victories or success. It should be used properly and provide valid and reliable results for coaches and athletes to improve performance. That is why it becomes important to involve the whole sports community in the development of these new methods. In fact, a new technology should also bring great responsibility in the development and use of it by coaches and athletes. Coaches should be aware of these new trends and developments to better use it. So, they must continually update their knowledge and perhaps be helped by a multidisciplinary team composed of physiologists, biomechanics, but also by equipment technician or even an engineer.

The possibility of easy transportation and real-time evaluation provided by wearable devices and sensors determine a step forward in the methods of evaluation and training control. There are great possibilities of controlling and evaluating every little parameter that should influence performance, some of them impossible some years ago. For example, today is possible to give real-time feedbacks regarding the movement performed or even to perceive the real workload for the body in response to an external load. Miniaturized accelerometers and gyroscopes, visual markers and biomechanical data obtained have been the main reference for coaches and athletes. However, there is a vast amount of technology that is being investigated and developed. For instance, technological innovations are been applied to textiles that can be embedded by physiological sensors, allowing interactive analysis by athletes and sports professionals. All these innovations allow optimized learning by sharing real-time data to all sports community and researchers, connecting the expertise and experience and increasing the knowledge for all.

3. Technology and organizations in sports

The technological innovation is also an opportunity for the organizations to reorganize their activity, the follow-up to clubs and athletes during their preparation. Most of all, the organizations have now the tools to provide the best experiences for the spectators, during a competitive event or even to provide the best information they need throughout the season. Nevertheless, we must be aware of several problems related with big data provided and with commercialization. For instance, Is anonymization still effective protecting users against tracking and profiling? In this new reality, is there a proper role for individual consent? How to lead with personal big data problem? What should it be confidential or not? These are some of the questions that easily arise in this new world and are transversal to all realities.

Sports require flexible organizational structures, capable of responding to the challenges of a society in continuous and rapid change, in an environment of social responsibility, respect for high ethical values and transparency. These assumptions meet some indisputable current realities. There is a need to re-adjust organizational administrative procedures, increasing

organizational efficiency and response regarding the institutional mission. There is also a need to increase the attractiveness of new practitioners and spectators, especially in those countries with the lowest rates of systemic practices. It is in this context that sports community must face the challenge of a technological revolution, seeking for the opportunities in all its organizational pillars in sensitive areas as marketing, communication and human resources management. This should be thought of based on a sustainability plan that will make decision-making increasingly competitive and efficient.

4. Technology and commerce in sports

It seems clear the great potential of technology in sports-related context. The development of wearable technology, monitoring systems and apps for phones and computers constitute not only an opportunity for maximizing performance, for improving physical tasks according to a personal objective, for reorganizing institutions and sports events, or redefine the role of coaches, athletes and spectators in sports, but also a business opportunity for many companies.

Several current technological brands and companies have been focusing a lot on the technological side of sports-related subject. These developments have ensured many partnerships with globally recognized organizations. And we are not only thinking on evaluation and controlling methods usually used by coaches and athletes. These technologies allow a full and real-time update, which also brings benefits to fans, who now have available a series of statistical data to track the performance of their idols.

Besides developing state-of-the-art technology for the sports-competitors, several commercial brands identified, a possibility of investment and profit. But several questions arise in this "battle" for the best service and price, seeking for profits. Should we trust in all the data provided by all the emergent and innovative technology? What about the validity and accuracy of the measurements? Is all the data reliable?

5. Conclusion

There is still a long way to go, but we must believe that the technology applied to sports represents an open door to new arising knowledge and potentiation of the sports phenomenon. With the rapid increase of technology applied to sports and physical activity, there are some questions that should be discussed by the sports community. Probably, sooner or later, regulations will have to adjust to what might be questioned as the new doping emerging from modern society, the technological innovation. Moreover, some roles should be redefined and organizations should be restructured to take advantage of the new features provided. Nevertheless, one should not forget to comply with the ethical standards and confidentiality when required.

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Section 2

Technology Towards New Thoughts in Sport

Chapter 2

Innovative Technology for High Performance and Mass Participation Sport

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Additional information is available at the end of the chapter

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Abstract

The chapter analyzes technological innovations used in high-level sport and how mass participants have and will benefit from these advancements. The authors discuss progressive practices of different successful sporting nations. The chapter debriefs high-performance facility development and utilization practices, as well as examples of modern equipment and technology being applied in multiple high-performance athlete service areas, such as general fitness, sport-specific training, restoration, nutrition, medicine, and psychology. This section also emphasizes examples of national and local high-performance technology practices for enhancing mass participation, such as evolving networks of comprehensive multisport training centers available for nurturing every possible age and socioeconomic group. Finally, suggestions are made to provide communities, in partnership with universities or local military installations, with recreation and sport technologies which are free or affordable for all, including instructions enabling everyone to utilize and enjoy the new technologies.

Keywords: sport technology, high performance, mass sport

1. Introduction

Throughout history, sport participants have benefited from new methods of fitness training, adaptation to extreme conditions, innovative medical care, and technology originally developed for elite military personnel. These advances are passed down to general troops and, finally, to the masses. Today, the military continues to drive fitness through sport, but

elite sport itself, when managed systematically, is becoming a leading force for mass sport participation and technological advancements, ultimately benefiting everyone [1–4]. High-performance (HP) coaches now lead teams of biomechanists, physicians, endocrinologists, engineers, and other technology specialists, developing systems and structures for the most effective and efficient preparation of athletes to competitions. Developmental level coaches and sport administrators, in turn, promote mass participation in order to maximize the pool of potential elite athletes with the ancillary benefit to their communities' well-being [5, 6].

Many advanced technologies originated in government-supported military, elite sport, or rehabilitation research programs. Over the period from 1927 to 1946, Harvard University's Fatigue Laboratory, backed by US federal funding, researched topics in the physical chemistry of blood, exercise physiology, nutrition, aging, and the stresses of high altitude and climate [7]. Beginning in 1941, many of the research reports stressed the physical fitness of soldiers, the energy cost of military tasks in extreme heat and cold, as well as developments in clothing and equipment for extreme conditions [7]. More recently, the Massachusetts Institute of Technology's Institute for Soldier Nanotechnologies [8], founded in 2002, developed new devices and textiles for health monitoring, wound healing, and atmospheric and environmental adaptation.

In the former USSR, studies of both mass/elite aspects of sport were coordinated by a central research institute, established in 1933, with studies undertaken at sport research institutes and sport universities in each of the country's 15 republics. Expert groups comprised of coaches, sport doctors, and scientists were formed in the 1970s to advise elite sport teams. The successful national USSR wrestling and boxing teams, for example, were serviced by a group of 40 specialists in pedagogical science, medicine, psychology, physiology, biomechanics, biochemistry, and engineering. The Russian scientists of the twenty-first century applied the wrestling research results to 13 other disciplines [5]. The Russian 2012 Summer Olympic sports were supported by 41 sport science groups, winter sports by 15, and Paralympic sports by 26 teams of scientists. This tailored method of sport science support has been adopted and expanded by China. There are six national laboratories and a team of 30 scientists helping national squads. To integrate resources, the Action Project for Olympic Technology has collaborated with institutions such as Beijing's Municipal People's Government, the Ministry of Education, the Chinese Academy of Science and the Commission of Science, Technology, and Industry for National Defense [5]. Of eight successful sport nations studied by Digel [9], sport science was particularly prominent in Russia, Australia, and Germany, while special research institutes and advice centers were also established in China, France, the UK, and Italy.

The government of Canada provided funds to create the Own the Podium (OTP) program for international sport success, especially for the Vancouver Winter Olympic Games, which the country hosted in 2010. In 2004, the OTP created a 5-year CAN$8 million project called the "Top Secret Project." This project sought to use science and technology to optimize the Canadian winter athletes' performances. Top researchers in Canada worked on 55 projects prioritized into four areas: competition clothing, ice sports, snow sports, and performance [10]. The Top Secret Project investigated super-low-friction bases for snowboards and how curling brooms melt the ice during sweeping. Scientists used a missile guidance system to track skiers and built a giant catapult, a type of human slingshot, to hurl speed skaters into a turn to

practice cornering [11]. The Canadian long-track speed skaters raced in space-age bodysuits designed by the Japanese Descente apparel company in collaboration with the Canadian National Research Council's Institute for Aerospace Research and the Speed Skating Canada. The suits were the culmination of 4 years of research and testing and are more aerodynamic than human skin [12]. These new technologies very quickly become adopted by opponents and then by recreational participants.

The following sections reflect key components of an HP management model emerging across the world and currently being utilized by organizations responsible for both mass/elite sport participation [7, 8]. Each section below offers examples of several methods driven by HP sport while also proving beneficial to mass participants.

2. General fitness

Appropriate *fitness testing* has great unrealized potential as a critical component within physical education and mass/elite sport [13]. An examination of the differences in the most often implemented youth fitness test programs across the world, particularly the Chinese National Physical Fitness Test (CNPFT), European ALPHA-FIT (Assessing Levels of Physical Activity and Fitness), American FitnessGram®, and Russian GTO as the most widely implemented youth fitness tests in Asia, Europe, and North America, indicated key shared test components (i.e., aerobic fitness, muscular strength and endurance, and flexibility). However, Internet-based physical activity assessment and interactive technology were only utilized by GTO: its webpage (http://gto.ru/) offered high-quality videos with audio and text instructions, supported by interactive instant messaging/texting and voice assistance by trained operators.

Uniquely offered for each age, GTO is highly individualized, employing swimming and skiing as optional testing items in addition to running. Lifestyle-related skills such as camping, recommended weekly physical activities, and fitness knowledge tests were only included in GTO. While comprehensive and technologically advanced, GTO can be implemented at no cost to participants: hiking and camping, swimming and skiing, pneumatic and electronic weapon shooting coincide with many schools' curriculum and the lifestyles of many Russians. CNPFT can be costly, requiring expensive equipment to test Vo2max (i.e., US$4000 per unit). The FitnessGram® in the US required a budget for equipment (i.e., sit-and-reach texting box, curl-up strips, and skin fold flips) and assessment software (i.e., US$599 for the first year and US$149 for renewal). The ALPHA test version developed for schools uses a dynamometer, costing around US$350–450, and other ALPHA versions may also require a skinfold caliper costing about US$250 [13].

Only GTO was designed to connect testing results to sporting programs, requiring a database created in the USSR. Before competing in a particular sport, USSR participants achieved the highest age appropriate GTO results and then progressed through 10 sport-specific ranks. Russia and China adopted this sport qualification system. Each rank requires specific results against increasingly stringent criteria revamped in each Olympic quadrennial through research and consultation. Russian sport scientists extended the USSR system from 60 sports in 1980 to 143 in 2011. This required advanced information management technology, playing

an important role in the success of mass/elite sport in the former USSR and in China. Sport participation rates in China are high [14], and 430 million Chinese have met governmental fitness goals [15]. After entering the Summer Olympics in 1980, China advanced to number one by gold medal count in 2008. These Chinese results have been achieved since 1958 when an integrated mass/elite sport plan set a target of 200 million people passing GTO tests; 50–70 million reaching competitive level; and 10–15 million becoming elite athletes [15]. Using big data analyses, GTO advanced eight times since it began in 1931. The unique 2014 GTO guidelines included 11 gender-specific age stages from six to over 70 years old, using over 20 mandatory and optional tests [13].

There may be a need to develop a global fitness test program as monitoring youth fitness from the international perspective is of concern. Fitness tests should include all age groups integrating knowledge tests, optional test items from Eastern exercises such as yoga, and various alternatives to running. Also, tests could be made easier to administer by participants by lowering costs. Stronger reward programs, and better instruction and promotion strategies using the latest Internet and mobile telecommunication technology for the worldwide population to track their fitness changes over their life span by lifelong fitness testing on a regular basis, should lead to improved health worldwide [13].

3. Sport-specific training

To assist mass and elite participants with healthy progression to the highest desired level of performance, sport authorities are starting to publish *long-term athlete development* guidelines specific to each sport. Assisted by statistics as well as computer and medical monitoring technology, scientific and individualized load selection and recovery intervals are becoming better understood and used for mass participants, with a critical role played by *periodization*—a systematic structuring, or cycling of short- and long-term training programs, to provide optimum performances at the required times [16]. Training concepts such as periodization have been passed from HP scientists and coaches to mass participation programs and are becoming part of education and training plans required for each coach in the twenty-first century. If taught to all as a component of PE, periodization will help recreational and competitive participants to improve their performance efficiently and minimize risks of injury and overtraining, thereby increasing productivity and reducing national healthcare costs.

Periodization can be useful in many facets of life: preparing for many events (e.g., winter season, school tests, work projects, and presentations), pacing work and rest every day, week, month, and year, as well as organizing our thoughts. While periodization played a crucial role in the development of sports science from 1970s after it was pioneered by Leo Matveev from the USSR, other advanced training concepts offering more quantitative and personalized approaches based on advanced computer and medical monitoring technology have been developed for Soviet athletes. In the twenty-first century, these sophisticated methods are becoming available to mass participants around the world. The increasingly individualized

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periodization methods require more advanced technological support in order to monitor, analyze, and correlate medical and performance indicators. The technological capabilities provide both better performance and more developed, complicated and healthy training methodologies.

Siff and Verkhoshansky [17] discussed the concept of *cybernetic periodization*, in which various forms of feedback are used to make decisions in training protocols. Types of feedback gathering methods include the Rate of Perceived Effort, which the athlete gages on a scale of 1–5, where 5 is the most strenuous and 1 is the least demanding. Another method of gathering feedback is the Rate of Technique. Here, the coach gives a score on the technique efficacy of the lift. This can be done using different rating scales. Optimally, the coach and the athlete communicate to direct training intensities and volumes. Siff and Verkhoshansky [17] also discussed using other methods of monitoring in order to guide practices, prescriptions, recovery periods, etc. Such tests include measuring heart rate, soreness gaging by finger palpation, blood pressure, work capacity in a back squat, reaction time, various methods to test an athlete's velocity, as well as self-perception ratings for an athlete's mental state. Recently, in the US, *autoregulation* has been applied to vary training load prescriptions, where athletes use variations that occur in their performance daily and throughout the week to customize intensities and volume used in training. Recent research has found autoregulation approaches to be superior to linear periodization models where set numbers were prescribed over time [18]. While the above advanced training methods are becoming available to the mass participation population, coaches must acquire knowledge about the related physiological principles and technological skill in order to monitor one's biomedical parameters pushing athletes to levels where high levels of supercompensation and improved performance can occur.

The evolution of planning training strategies for athletes accurately and effectively may lie in the combination of systemized and planned periodization schemes, with goal intensities and volumes varied in a cyclical fashion, combined with monitoring and autoregulation techniques being applied to help in the process. This concept is referred to as *parametric training*, developed during 1970s–1990s by the USSR researcher Sergei Gordon [19]. Parametric method offers an alternative to the classic periodization approach, particularly in studying the development of an individual athletes' special work capacity while devising a season plan based on adaptive abilities rather than sheer training volume [19]. The method is well documented in Russian scientific and methodological literature [20] based on over 30 years of data collection and testing of training methods that produced a number of world and Olympic champions since the 1950s when Soviet sports science was heavily financed and multiple research data banks were developed. Each Olympic sport was meticulously studied and the information was processed through associated research centers [19].

One of Gordon's former doctoral students, Sergei Beliaev, consults on parametric training as the President of Super Sport Systems [19], a company that markets this proprietary training technique. The Super Sport Systems' Internet-based software was developed by the Innovation Center for the Institute of Theoretical and Experimental Physics in Moscow. Since its inception in 2001, Super Sport Systems' computer-assisted parametric training method has

been used by more than 3500 coaches from more than 50 countries by 2015. It is particularly beneficial in endurance sports: at least 5 of the top 25 American coaches in swimming disciplines were Super Sport Systems' clients in 2012 [19].

The essence of parametric training is to manage specific training variables and to maintain one parameter of training constant while changing the others. The selection of the "managed" parameter will influence the time at which the body exhausts its adaptive reserves. Therefore, the abilities developed during the training season can be related to the strategies which are most effective in each particular case or seasonal phase. Parametric training is, therefore, a multidimensional concept defined by such variables as time of work, time of rest, distance of repetitions, speed, etc., and on many levels, with multiple combinations of different training strategies. The knowledge of the relationship between specific training variables and changes in athlete's individual condition is used to create winning training strategies. The training process requires calculation of changes in related physiological parameters (e.g., heart rate, VO_2, concentration of lactic acid in blood, heart output, and heart stroke volume) over time, during different stages of a season, and in relation to strategic purposes. Dr. Gordon and other leading American and Russian sport scientists and coaches continue to further develop the method [19].

Parametric training and other individualized training methods are going to remain a luxury for the elite with little impact on public health until generic age and gender-specific fitness requirements and training instructions based on basic periodization are taught to everyone at school and then used for rewarding fitness among all age groups. Fitness systems such as the Chinese CNPFT, European ALPHA-FIT, American FitnessGram®, and Russian GTO are instrumental in this process and can be further advanced to bring global populations to the next level of understanding, thereby improving productivity and reducing healthcare costs. New technologies developed with support from governments and corporations are going to continue driving future advancements of both general fitness tests and sport-specific training methodologies and their availability and affordability for everyone.

4. Sport restoration and medicine

US Olympic Training Centers (USOTC) lead elite and mass participants in the use of advanced technology. The utilization of *variable, sequential air-modulated compression and massage equipment* (i.e., Norma Tec) is increasingly being utilized by high-level athletes with the intended goal of facilitating faster recovery. These modalities are used in recovery labs within training facilities, particularly USOTCs, but can also be found in retail stores that cater to endurance athletes and units can also be purchased for home use. A USOTC-based study [21] showed that the peristaltic pulse dynamic compression can accelerate and enhance recovery after the normal aggressive training that occurs in Olympic and aspiring Olympic athletes. The data lean toward the benefit of this training modality to assist in recovery and may have its efficacy be increased when combined with other restorative methodologies discussed in this chapter.

Hivamat and Theragun are two varieties of *handheld vibration therapy* devices based on deep oscillation therapy currently utilized in a variety of training and fitness settings including

USOTCs, professional and college sport therapy rooms, X Games athletes as well as personal/nonprofessional/elite level athletes use in strength and conditioning/CrossFit facilities as well as home use. Each modality provides percussive vibration/massage to purportedly reduce muscle and joint pain, improve mobility, and enhance performance by increasing blood and lymphatic flow, breaking up scar tissue, reducing muscle proton and hydrogen build up, and activating the nervous system and muscles. Hivamat, which is predominantly utilized within the medical and rehabilitation field, has been identified within the current research to effectively address lymphatic fluid buildup with less data on the effectiveness in managing in edema and/or muscle damage [22–26]. Theragun, however, although it is more widely utilized due to its lower cost, ease of use, and few contraindications, has limited evidence of its validity. As the utilization of these modalities increases, the likelihood of validated performance and restorative benefits is likely to surface.

Neuropriming is a process of using electrical stimulation to increase plasticity in the brain prior to an activity. According to Sharma et al. [27], neural plasticity can be defined as the ability of the central nervous system to adapt in response to changes in the environment or lesions. Used in the product Halo, this process purports to decrease the amount of input required for neurons to fire, and helps neurons fire together, enabling more rapid strengthening of connections in the brain. When paired with quality training, this results in increased strength, explosiveness, endurance, and muscle memory. Although most of the evidence is anecdotal for the product Halo at this time, many high-level athletes and coaches use this technology. According to Halo [28], athletes training for strength- and power-intensive sports received neurostimulation treatment in the form of transcranial direct current stimulation (tDCS) from the Halo Neurostimulation System and in turn demonstrated significantly greater improvement in their jumping ability compared to nonstimulation athletes. One specific example highlighted by Halo identified that even with identical training, Halo Sport users on the USA Ski team produced 13% more jump force compared to a control group, and reached goal performance 5 days sooner compared to a control group (45% faster). While these USOTC methods have anecdotal and some published evidence that they enable athletes to improve performance and recovery, more does not always mean better, and the abuse of these implements could occur when used without professional instructions.

Dry needling (DN) is used to treat musculoskeletal injuries, pain, and muscle tension reduction [29–31]. Most of the current literature has shown the effectiveness of DN on latent trigger points [32–34], but there has also been success in its use to increase range of motion (ROM) after a muscle strain [35] and after an ACL reconstruction [30]. Myofascial pain is a common form of pain that arises from muscles or related fascia and is usually associated with myofascial trigger points (MTrP) and musculoskeletal injuries [33]. An MTrP is a highly localized, hyperirritable spot in a palpable, taut band of skeletal muscle fiber [34, 36]. Research has found that MTrPs are reported as a primary source of pain in a majority of musculoskeletal pain patients, as well as in many other types of patients from chronic widespread pain to headaches [37–40]. The most common method for MTrP is inserting a needle directly into the MTrP and leaving it in place for a short period of time (30 seconds–1 minute) [36]. A modified version of this technique is to oscillate the needle in and out of the MTrP during the treatment for the same amount of time [41]. Both techniques are effective when a local twitch response is elicited [42], most likely as a result of depolarization of the involved muscle fibers, which

expresses as local twitches [43]. Once the muscle has stopped twitching, the spontaneous electrical activity subsides and the pain and dysfunction decreases [33]. This form of intervention has seen good results in the treatment of MTrPs [33, 34, 44]. In addition to focusing on MTrPs within a muscle to release tension, there have also been studies that focus on MTrPs to increase ROM, short-term muscle endurance, and return to performance in elite athletes [45]. Most importantly, DN can help with the management of rotator cuff, as part of a conservative therapeutic intervention plan instead of surgical intervention [31]. More elite and mass sport participants may benefit from DN as health insurances in Western societies from Australia and Canada to the UK and the US increasingly cover Eastern methods of medicine, and the acceptance of formerly unique, nontraditional methods of treatment and prevention become more accepted and available to everyone in the West.

Despite the broad, varied, and long history of *cupping* as medical treatment, the technique fell out of favor in the West until a relatively recent resurgence. The common theme in all cupping practice is a suction applied to the skin using a cup-like tool [46–48]. Historically, these cups have been made out of bamboo, glass, or metal [49]. The suction can be created with a machine, as with pulsatile cupping, a hand pump, commonly included in sets of plastic cups, or with a flame inside the cup prior to application. The two major divisions of cupping are wet and dry cupping (DC) [48]. Wet cupping, also known as "traditional cupping," involves an incision or needle prick that draws blood and other bodily fluids. The cup is then applied over the open skin to further draw fluid and blood into the cup [48, 49]. This type of cupping is practiced more in Eastern countries, such as China. During the practice of dry cupping, only the suction is applied and the skin remains intact [48]. In the US and Canada, medical practice acts regarding the incising or breaking of skin vary across professions and across states, so DC is a more appropriate technique for the treatment of musculoskeletal injuries. Even though dry cupping does not involve direct skin incisions and the availability to the tools is more widespread, those who use cupping as a therapeutic intervention should do so by an individual who has training in the skill to reduce the risk of further injury or harm to the treatment area.

DC can be performed in several ways: static, massage, or pulsatile. Traditional static cupping involves placing the cup on the skin with suction and leaving the cup in place. The patient may be moved through passive or active range of motion during the treatment, but the cups are not moved [46, 49]. As the cups are moved across the skin, it is referred to as cupping massage. Cupping massage combines the effects of cupping with those of manual massage [49]. Pulsatile cupping is a modernized form of cupping involving the use of a mechanical device to generate a pulsatile vacuum [47, 49]. During this form of cupping, the amount of suction varies throughout treatment, whereas during static cupping and cupping massage, the suction remains consistent throughout. Pulsatile cupping is designed to combine the effects of cupping with pneumatic pulsation therapy [49].

The effects of DC have centered around pain relief as most of the research in dry cupping has focused on treatment of chronic pain in the general population. Pain relief has been found to be a major effect of cupping as reported in most studies involving DC, which supports the more widespread use of it as a therapeutic intervention [46–50]. In the athletic community,

there is often a need for immediate pain relief. The work by Cramer et al. [49] was one of the first studies to describe a decrease in pain reported with just one cupping session. As DC technology and methods are becoming more widespread across the world, more instructions and training in the cupping skill are needed.

HP athletes and mass participants in many sports have been using *water and heat treatments* based on old national traditions. For example, the following traditional Russian multimodality approach [51, 52] is used at the end of a typical training week:

- three sauna sets for 10 minutes each in temperature 70-80C/158-176F with humidity of 60%;
- during minimum 3-minute intervals between sauna sets—cold baths or showers;
- during second and third sauna set—a gentle beating massage by a fragrant bundle of leafy birch or oak tree twigs to improve blood circulation, intensify skin's capillary activities and metabolism through phytoncides and essential oils released by the twigs;
- after second and third sauna set—hand/self-massage; after third set—swimming;
- concluded by 30-minute rest in warm conditions.

According to Semenova [52], tired muscles are best restored by laying in sauna immediately after the workout for two sets—four and then 5 minutes, with 8- or 10-minute intervals, in about 90-100C/194-212F temperature with 20% humidity. Semenova's [52] work highlights the need for further research and advice specific to various medical conditions and performance objectives. Further investigation of global sauna methods by sport medicine researchers is needed to optimize the use of sauna for various objectives and periodization cycles of sports, and avoid adverse effects of incorrect sauna use. Therapeutic facilities for restoration, particularly spa/Jacuzzi and sauna, are a common feature of recreation centers worldwide. Further advancement of these facilities and instructions for correct and evidence-based use will make regeneration and immune system strengthening available for HP and recreational participants.

Balneotherapy is a cost-efficient restoration method with potential for greater use by elite athletes and the masses. Baths with natural substances such as sea salt, sodium chloride, and sulfur hydrogen are hydrotherapy methods used for mass/elite participants' overall regeneration and to treat specific conditions [53, 54]. Underground healing spring water is the main component of traditional European balneotherapy. In countries like Austria, Czech Republic, Germany, Canada, and Japan, spa treatments are covered by health insurance or as regular medical treatment in the public health care system, an approach beneficial to both athletes and the masses.

One of the most advanced balneotherapy technology centers is in the Russian Black Sea city-resort of Sochi, where mass/elite athletes utilize the region's 250 training facilities and resorts. As part of the US$US3 billion increase in governmental support of sport leading up to the 2014 Winter Olympics, the new hydrothermal complex at the Sochi national training center was equipped with seven different kinds of hot rooms and saunas as well as pools for

hydromassage and rooms for other types of massage [55]. The government started developing this balneotherapy resort in 1934. Scientists led test boring, drilling down 2000 meters obtaining water with one of the world's highest hydrogen sulfide concentrations. The physiotherapeutic balneological complex has more than 700 baths, providing up to 6000 spa procedures a day [56].

In the US, one of the most established sulfur hydrogen centers is Safety Harbor Resort and Spa in Tampa, Florida. The 2000-year-old springs are located beneath the resort. However, no medical instructions for the use of the mineral spa are provided. In the US, more research is needed to substantiate the healing claims of balneotherapy before the American government's medical and sport specialists could utilize this natural method for treating and preventing illnesses on a mass scale as is done in Europe, such as treating common disorders like back and muscle pain [57–59]. Recreational users may benefit from specific recommendations by sport scientists for the use of ancient and modern methods of regeneration for healthy training. These techniques can be questioned, and Western sport scientists would argue there is a scarcity of research to support these methods. However, with increasing use in medical services around the world, particularly in sport and military, where a speedy recovery from exertion and injury is important, trying all possible, inexpensive, and potentially less harmful physiotherapy and nonsurgical means should be given careful consideration.

5. Nutrition

Sport scientists have developed recommendations for elite athletes that are useful for mass participants and public health. The USOC Sport Performance Division published athlete eating guidelines on the USOC's Internet site, which, among other recommendations, advises to limit "sports" bars and drinks as they can deter body weight goals and can replace more beneficial calories from whole foods. Food processing technologies have a long way to develop before they could provide healthy nutritious options to HP athletes and mass participants.

Important for sport participants are technologies used to produce *micronutrient supplements* which have long been practiced with beneficial results. Numerous studies have shown a correlation with increased calcium intake and decreasing occurrences of stress fractures while increasing bone mineral density. Evidence exists correlating vitamin D supplementation with fracture prevention [60]. Research has found sustained supplementation of antioxidants to reduce the symptoms of exercise-induced muscle damage, i.e., muscle soreness, swelling, and increased intramuscular proteins circulating through the blood [61].

New technology and processes in *molecule refinement* have allowed for a more effective energy delivering liquid supplement for athletic performance and nutrient timing for positive body compositional change. Vitargo, for example, a refined starch-based product, has a high molecular weight in comparison to maltodextrin products, like Gatorade. Vitargo's preworkout and workout supplement labeled Vitargo S2 has been shown to have faster gastric emptying times, resulting in a faster rate of replenished muscle glycogen. Vitargo has also been shown to increase work output for a longer period of time as compared to maltodextrin products [62].

Current findings show modern manufacturing processes allowing more effective energy fueling for athletes and a superior postexercise restoration tactic. Vitargo is an example of providing an ergogenic aid for HP athletes and beneficial for all.

Healing food lists are incomplete requiring more research, analysis, and advancement of new and forgotten technologies. For example, kefir (yogurt's cousin), is only starting to benefit Western immunostrengthening food lists while still going through scientific validations [63] and understanding of its production technology. We will be able to take full medical advantage of culturally unique culinary solutions when isolated studies on particular foods and supplements are systematically coordinated to achieve specific health and performance improvement objectives. HP sport can lead masses in such research of nutrition: coaches and athletes experiment with advanced nutritional concepts and seek advice on such emerging dietary aspects as, for example, using antibacterial, anti-inflammatory, and bioactive foods; separating foods with different speeds and dynamics of digestion, cross-enhancing different foods as well as integration of bioactive substances and adaptogenes.

Scientists could improve both mass/elite performance, ultimately benefiting public health, through more evidence-based advice on the cross-benefits of various foods. Intuitive practices over time have led to food combinations. Such combinations as borsch and shchi soups are a daily must for many Eastern Europeans, particularly for school and sport lunches. Performance and health benefits of some soups are known in the West, especially chicken broth as a remedy for the treatment of colds and flu [64], but many soup benefits and possible harms from incorrectly prepared or canned soup [65] are to be determined by researchers. In order for mass/elite sport menus to improve performance and strengthen participants' health, effectiveness of different food combinations and preparation technologies must be confirmed through systematic studies commissioned by organizations independent of food producers, possibly by public health and sport agencies.

6. Sports and exercise psychology

Sport and exercise psychology practitioners maintain two essential objectives within the field of study and sport science; to teach mental skills in the enhancement of performance based on an understanding of the principles of how physical and motor performances are affected by one's psychology; and to promote psychological development, health, and well-being through physical activity while relying on those same principles [66]. As indicated in previous sections of this chapter, many innovations emerged from military labs. Concurrently, North American, European, and Australian university labs have spawned most of the high-tech innovations currently being perfected in applied sport and exercise psychology settings. Two noteworthy innovative advances having an impact in the applied arena of sport psychology consultation with Olympic athletes, professional organizations, and many top university athletic programs are training *biological self-regulation* skills and improving *symbolic learning techniques.* Biological self-regulation methods have been practiced for eons but high-tech advancements, such as *biofeedback* and *neurofeedback,* used to enhance sport performance

bring the technology to just about any conscientious sport participant. Symbolic learning, aka imagery or visualization, is regularly practiced in a multitude of sport settings. *Virtual* and *augmented reality* compliments the imagery practice. Due to achievements in computer miniaturization, increasing affordability of technology, and increasing portability, these innovations are filtering down to the masses. Consequently, the potential for improving mass participation in a variety of sporting activities in conjunction with both of these technological innovations is high.

As used in sport training, *biofeedback* and *neurofeedback* help athletes become aware of and eventually regulate biological functions; physiology and brain wave activity, respectively. Biofeedback involves the use of instrumentation to capture physiological measures that are immediately displayed back to the person on a wristwatch, smart phone, or laptop computer. *Biofeedback training* (BFBT) uses biofeedback to enhance skill development in one's self-regulatory capability toward heart rate, heart rate variability (HRV), respiration, muscle tension (electromyographic feedback), or skin conductivity (electrodermal feedback) regulation. As just one example, the biathlete that needs to slow down heart rate while preparing for the shooting portion of the event can practice this with BFBT. Neurofeedback training focuses on regulating brain wave activity. Medical treatment of assorted brain and cognitive functioning issues using neurofeedback is beyond the scope of this article. For sport training purposes, neurofeedback targets the brain wave activity consistent with relaxed but highly focused concentration as required in many sport tasks, including targeting and shooting skills mentioned with the biathlete above.

These biological systems, traditionally thought of as outside of voluntary control in the "western philosophy" tradition, operate under the influence of the autonomic nervous system. Eastern philosophy adherents, however, have been practicing biological self-regulation techniques for millennia. BFBT has been used in medicine for many decades [67], and while studies of BFBT in elite level sports studies date back to the 1970s, the volume of research has growing rapidly within the last few years. Recent studies illustrating the use of BFBT include speeding up reaction time for basketball players [68], penalty shot accuracy of hockey players, and a "relaxed ready state" with gymnasts [69]. This chapter's second author has used BFBT both with collegiate athletes and with nonathlete students, namely for anxiety reduction, emotion regulation, and sharpening focus [70, 71]. For a more thorough review of BFBT and neurofeedback research in sport, see [72].

In exercise psychology, Ekkekakis and Petruzzello [73] argued that BFBT can and will be effectively used to attract sedentary people to be more active. By enhancing awareness of physiological demand during exertive exercise, they theorized, it is expected more positive affect will emerge and exercise intensity suitable for each individual can be reached. The improvement of affect occurs when the BFBK helps the exerciser recognize aerobic tolerance levels, an important skill known to be related to enjoyment of the exercise activity. Often marketed as mindfulness training or meditation, companies like emWave, Unyte (formally Wild Divine), and the like sell effective software products and measuring equipment that are cost affordable (US$300–$500). Thought Technologies out of Canada produce more expensive (ranging from US$2000 to US$10,000) and sophisticated complete biofeedback and neurofeedback systems.

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Although imagery, using all of the senses to create or recreate movement experience in the mind, has been a staple in sport psychology mental skills training, virtual reality (VR) offers a high-tech twist. When imagining sport skills, athletes develop a mental blueprint by creating a motor program in the central nervous system. Understanding and acquiring movement patterns is referred to as symbolic learning theory [74]. VR improves upon traditional imagery training by radically enhancing the sensory experience. Ramgopal [75] profiled a college field goal kicker who uses VR to improve technique in Stanford University's VR training room. NBC Sport broadcasted a piece showing how the National Football League (NFL) uses VR to get starting quarterbacks ready for live action and how college programs screen quarterbacks for potential starting positions. For the price of popular gaming systems, virtual reality games that involve movement, Wii games as one example, have been bringing this new technology to a wider spectrum of people, increasing a culture of movement. The technology is still improving but the trends of mass consumption of this new technology are clear.

Combined with the latest video analysis methods (Dartfish™, Krossover), video feedback training sessions between coaches and athletes to enhance practice and competition preparation are increasingly an essential of any organized sport program. Due to the technologically proficient generation of today, these powerful and sophisticated video training methods, in true grassroots fashion, seem to have been led by the athletes themselves. Relative to the exercise and health consciousness sector, VR methods can be optimized with mass sport participants by introducing new sports and movement experiences that can be tried in a safe environmental setting while not sacrificing intensity of the experience. Legrand et al. [76] examined this with over 100 university students and found that their VR protocol resulted in greater enjoyment in self-selected exercise. Such research is limited at this stage and more needs to be learned about where and how high-tech applications can be broader.

Whether these technological advances are cultivated in military training or the university research and sport team setting, the speed with which advancements trickle down to the masses continues to increase. Biofeedback and imagery tools, for example, are wonderfully suitable for college course units. This chapter's second author introduces these applications to athletes and recreational exercisers alike, as well as to students undergoing coaching education training and physical education preparation. University coaching education curricula typically orient and train students to enter at the youth sport level coach, and physical educators to teach and inspire lifelong movement learning. As most institutions in North America and Europe naturally cultivate a civic relationship within the community they are located, advances such as the ones described in this section find their way to the health conscious populace more quickly than ever before.

7. Equipment and facilities

The *high-altitude simulation* technologies developed for elite athletes are now benefiting mass participants. To improve performance of US distance runners, Nike House was opened in

2001. It was equipped with US$110,000 worth of air-thinning technology. In the five-bedroom 3000-square-foot bungalow, oxygen was partially removed from the air, simulating altitudes from 9000 to 14,000 feet, which helped runners to increase their red blood cell count by 11%. Nike House was decommissioned in 2005, and the athletes involved with the Oregon Project found their own accommodations outfitted upon request with reduced-oxygen rooms or sleeping tents [77]. Elite USSR wrestlers have been leading squads of mass participants in other sports training while wearing face masks and constricting chest expansion with elastic bands in order to reduce oxygen athletes breath in so when more of it becomes available, the athlete receives a competitive advantage [51]. While the success of Soviet wrestlers is supported by hard data and explanation of some specific practices, methods used to achieve this overall success are complex, interrelated, and applied by highly educated coaches and sport scientists [5, 51]. These methods should be considered integrally and should be implemented by qualified professionals. Training devices developed with limited expert advice and used in isolation from other necessary programs and conditions might not achieve expected results. One such sports training device used by athletes despite the lack of its empirical evidence and instructions for its effective use is the Elevation Training Mask 2.0, High Altitude Simulator, which was sold online for US$79 on Amazon.com.

Barns et al. [78] concluded that the Elevation Training Mask 2.0 showed promise for facilitating increases in aerobic training when used in conjunction with evidence-based High-Intensity Interval Training, but other studies showed less positive results, which should deter sport programs and athletes from investing in such a tool without more detailed investigation of this device and programs which could make it an efficient addition in reaching specific performance and health objectives, based on consultations with doctors and expert coaches. The use of similar equipment by inexperienced participants and without accompanying personalized programs is unlikely to reach desired results and is a good reminder for all involved in the sports industry to use empirical evidence and expert advice as a guide versus popular trends.

One trend that has been driving the development of fitness technologies has been *multijoint multipurpose exercises*. According to Stone et al. [79], the use of free weight, multijoint exercises is more efficient and produces improved results when compared to machine strength training. Many reasons account for the superiority, with major benefits coming from mechanical specificity toward athletic motor patterns, force application for sport, and velocity of movement causing a more effective training effect to be useful in the realm of athletic competition. Time is saved by using multijoint movements, also called compound exercises (e.g., doing lunge and lifting weight) are an efficient way to get a full-body workout done in less time, targeting multiple muscle groups at once and stimulating the athlete's nervous system and creating a more significant neuroendocrine response increasing the production, release, and utilization of testosterone as compared to more isolation-type exercises. However, machines are also increasingly used to achieve multiple training purposes for both elite and recreational participants. As recreation venues in every community of the twenty-first century are expected to include parks with play and fitness grounds as well as strength training and swimming facilities free or affordable for all, everyone needs skills and instructional programs to utilize these venues to achieve desired results.

Systematic efforts to build integrated hubs of multisport facilities and infrastructures which benefit both HP athletes and mass participants have resulted from adequate government support. Two sport hubs developed in different historical and socioeconomic conditions serve as models for the integration of facilities and programs. Each occurred before the respective country hosted an Olympic Games. The first being Moscow in 1980 and the second London at the University of Bath (UK) in 2012 [5]. In the Izmailovo district in northeastern Moscow, a sport hub was formed around a sport-oriented university. An important feature of both hubs was the integration of sport facilities and programs with their cities' socioeconomic infrastructures. Both hubs have been part of historical and recreational tourist destinations conveniently connected by public transport with the center of London in the UK and Moscow in Russia. Both hubs attempted to attract everyone to sport by giving children the same standard of facilities and coaching used by elite athletes. Elite athletes share the facilities with recreational users, inspiring community participation while producing world records [6]. Cities such as Melbourne, Moscow, Toronto, and Singapore placed successful bids for major events after attempts to build sport hubs integrating entertainment, HP training, and mass participation utilizing public/government resources. Many countries, from Australia, France, and Germany to Russia, China, and Cuba, contribute to equal opportunities for citizens by publically funding the best training conditions at both national and regional levels. National sport authorities could raise administrative efficiencies through the creation of more sport hubs. Coaches, facility managers, school administrators, teachers, sport scientists, medical and other sport personnel could be concentrated in these hubs. Sport and medical scientists could be invited to use sport facilities, events, and athlete data for research and further advancement. Well-planned public transportation systems could better connect residents with the hub's sport, educational, medical, sport science, and administrative facilities [5].

8. Conclusions

As these innovative approaches become more affordable, portable, and popular, the challenge will continue to be, how to bridge the gap between high-tech and common use appropriately? How can we design these new technologies so that the masses improve their lives? And finally, how can we effectively teach all users to interpret the data generated by the innovative techniques? The era of big data is upon use. When understood and used properly, the ultimate goal of mass participation fueling elite sport which circles back to mass sport involvement will be realized. These issues and recommendations given in this chapter should be considered by sport, health, education, and defense departments of national governments. Sport governing bodies, universities, and research centers, and corporations should be stimulated and coordinated to devote more effort toward studies, development strategies, and policies for technological innovations which benefit both HP and public health. While the marketplace continues to produce many of these technologies for the general public, sport science experts have to be present to smooth the transition from the lab to the household. The responsibility of bridging this gap falls on schools and universities, in coordination with local government officials, to revise training programs of sports scientists for this new age of big data analysis and individualization of these high-tech innovations the wider public can safely and effectively utilize.

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Chapter 3

How Technology is Bridging the Gap between Sport, Health, and Medicine

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Additional information is available at the end of the chapter

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Abstract

Stretching back to the ancient Greek Olympics, athletes have sought the mentorship of coaches as a means of improving their athletic ability. This tactic of seeking guidance from a master craftsman is still present in all fields from medicine to fitness. What has changed are the channels available to distribute those lessons. Modern advances in technology have made coaching simpler, convenient, and effective for people to receive world-class coaching regardless of the physical distance between them and their coach. This chapter will examine three topics. First, we will explore the benefits of having a coach guide you towards your sport or health and wellness goals. Next, we will investigate recent advancements in technology allowing coaches to reach more people while keeping them engaged and maintaining retention. We will then examine medical technology companies currently employing these strategies and how the success they are having with clients is transferable to the sport industry. Coaching has been around for millennia, what is new is how we use technology to improve the coach and client connection.

Keywords: health, wellbeing, technology, training, sports

1. The value of a coach in improving sport performance and general health

From the moment people are born, babies begin the learning process. Learning for people starts in the same way as many other mammals, with the chameleon effect. People imitate the basic fascial expressions of their parents as a chameleon copies the colors of its surroundings. Babies continue mimicking influential people in their lives through infancy, childhood, adolescence, and carry this skill through adulthood. People are constantly mimicking others

they admire from siblings, schoolyard peers, co-workers, and their spouse; we continue mimicking the people around us which we deem appropriate [1, 2]. These individuals act as social models to base our actions, they are inspirations in our life for how we are supposed to act in a given context. Whether it is intended or not, these people are our teachers, mentors, and coaches. They help us establish our identity and group mental models that we carry with us to our next social circle [1]. The chameleon effect is so strong and effective, that it was formalized into a proper learning method centuries ago. This method is commonly referred to as apprenticeships. Apprenticeships come in all formats, but staying within our scope, when athletes form apprenticeships with mentors, the mentors are more commonly known as coaches.

Looking back to ancient Greece, Egypt, Babylon, and Rome, apprenticeships were the backbone for building a skilled workforce [3]. This was the fashion for passing along skills from an experienced craftsman to a novice. Skills were passed along through observation and trial and error, and when adolescents came of age, they became valuable members of society [4]. Focusing on sports of that period, it is worth exploring ancient Greece's strong history with athletes and coaches as the founders of the Olympics. Athletes then as they do now pair up with a coach who is a master of their discipline to teach them the skills and knowledge of their sport.

The coach and athlete relationship went on in this manner for some period, focusing on different sports as the times changed, but always maintaining a basic mentorship approach. Although coaching techniques change as societies evolve, human nature adapts at a slower rate and thus coaching theory in its basic mentorship approach is relatively constant [5]. However, as we approached the modern era, the concept of coaching split. On one side, there was the British approach where sports were viewed as leisure activities. Athletes of this philosophy did not want to be seen spending too much time developing skills for the fear that they would appear to be trying too hard. On the other side, there was the American approach to sports. The Americans possessing a more competitive and entrepreneurial spirit saw the value in sport coaching. This cultural difference lead to Yale University hiring legendary head coach Walter Camp who took them to countless American-football championships over their Harvard University rival. Yale lost only four times to Harvard whom took the British approach in the first three decades of their teams' late 1800s/early 1900s sport rivalry. Now, just as Yale did then, athletes seek guidance from experienced coaches to teach them mastery of their sport [6].

Upon reaching a certain stage, people forget there is value in coaching. There comes a point in many people's lives when they feel they have learned enough from others and can learn the rest on their own. However, this could not be further from the truth as people and the game are constantly evolving. This need for coaching opens an opportunity for coaches to build a client base who are willing to invest the time necessary to properly mentor an athlete. Coaches are a combination of teacher, mentor, boss, and therapist. Therapist in the sense that coaches use psychological skills training such as leadership, goal-setting, self-awareness, and visualization in their coaching style [7]. Remember, coaches are not coaches if they have no one to coach. This makes it a coach's responsibility to show the value of coaching to those who are not currently involved.

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1.1. Even the best athletes have coaches

At what stage is a person considered so great at their craft that they no longer need the guidance of another? Colonel John Boyd was an Airforce pilot and military strategist commonly known for his creation of the OODA loop (observe, orient, decide, act). With that said, he was also well known for his desire to learn from a variety of disciplines and combine those disciplines together forming something new from something old. He would blend rules from a variety of areas brining a new perspective to an idea [8]. If you follow Colonel Boyd's lead, you could say learning never ceases, since you can always apply something old from one area to a new area and make it novel.

When watching any professional sports team, you can look to the sidelines and see teams' and individuals' coaches lined up and down the field or court. Regardless of how good an athlete becomes, they know they need a coach if they want to continue improving. Atul Gawande, a surgeon noticed his performance in the operating room had peaked. He reached a point where he felt he could not perform any better than his current state. Dr. Gawande had a similar feeling about his tennis game. He felt his tennis skills had plateaued years ago and now he was trying to hang on to what he once had. This was until while on vacation he encountered a tennis pro who reminded him how regardless of when we believe we have peaked, there is always someone available who can show us another angle or approach that we did not see [6]. Just as Colonel Boyd blends disciplines, Dr. Gawande was blending perspectives to create something better and improve upon what he thought was his optimal ability. Dr. Gawande applied his new insight from tennis to surgery and saw an improvement in both areas. It is important for coaches to keep stories such as Colonel Boyd's and Dr. Gawande's in mind when they encounter athletes who have determined for themselves that they are too good for coaching. Part of a coach's job is teaching, and these lessons are valuable insights into why we constantly need to challenge ourselves and improve.

1.2. Coaching the coaches

It's not just the athletes that need coaching to succeed, but the coaches. In a peer-reviewed article regarding leadership published by the researcher in 2018 [1], it was determined that time must be spent properly training coaches, so they can effectively lead their athletes. Furthermore, coaches are setting the standard for tomorrow's athletes and they need to be properly trained to provide the best leadership to these athletes. Learning through experience, and the art of followership were shown to be the best way of training future leaders. These two leadership development characteristics imply athletes need an environment where they can practice their craft and must be good at following their mentors lead if they want to improve. Coaches like all leaders, need to properly learn their craft in an environment that allows them to make mistakes and discover their unique coaching style. This is best accomplished under the supervision of a more senior coach with the trainee acting as her assistant coach. By allowing the trainee to encompass the role of an assistant, it allows for the trainee to create an image of leadership identity, observe and mimic mentors and coaches, make impacting decisions, manage perceptions, and develop a leadership style through trial and error. All of these benefits were present among leaders when the opportunity to learn through

experience was present. The second part of developing effective coaches is mastering the art of followership, which implies the notion that to be a good leader, first you must be a great follower (**Table 1**). Learning through experience will not be beneficial if the person placed in the leadership position is not open to be a follower and learn from their mentors. The old style of leadership knowledge being held onto by an individual working in isolation at the top is a thing of the past and has proven ineffective. Today's leaders must work collaboratively with a variety of people bringing different skills to the problem [5]. Thus, mastering the art of followership is a prerequisite for great leaders and will grant the coach positive mental models, collective efficacy, cohesion, challenge, an encouraging environment, positive self-conception, and self-sacrifice [1].

Real world application of training coaches can take place as a pilot program where coaches work with select athletes in a supervised environment where the coach can employ a variety of coaching strategies while receiving feedback from a mentor-coach who has been deemed qualified by previously completing the training or going through a certifying committee. Committees have been shown effective at improving inter-department communication and gaining valuable feedback [9]. This is exactly what coaches need when establishing their coaching identity. By undergoing a training program in a controlled environment, it provides quality assurance when the coach is introduced to a formal role representing a collegiate or professional sports team, trainer at a resort or health spa, or exercise physiologist working in a clinical setting. A service provider's main resource is their reputation and pilot programs are a proven method of introducing quality services.

Committees now have access to platforms such as GoToMeeting, Skype, and Zoom to communicate across the globe. This grants coaches access to the best committee to help them achieve their desired end state. In the past, people were limited to coaches in their vicinity. Those coaches may not have been the best fit for a particular client. Additionally, when clients or coaches moved, their relationship often dwindled until it eventually ceased. Now, coaches can continue working with clients even if vast distance separates them. The past decade has unleased the ability for people seeking guidance to have a hand selected team with members on different continents. This gives coaches the ability to form a coalition, combining their unique backgrounds for a client's particular needs and goals.

	Learning through experience	**The art of followership**
Leadership development framework	Create an image of leadership identity	Positive mental models
	Observe & mimic mentors and coaches	Collective efficacy
	Make impacting decisions	Cohesion
	Manage perceptions	Challenge
	Develop leadership style through trial and error	Encouraging environment
		Positive self-conception
		Self-sacrifice

Table 1. Leadership development framework: coaches can acquire the above traits when working with a mentor [1].

1.3. Individual coaching versus group coaching

Individual coaching and group coaching are two ways for a coach to engage with his clients. Individual coaching is more personalized and costly for athletes, whereas group coaching delivers a less personal approach with reduced cost to the client. Research by Losch et al. [10] discovered, although individual coaching and group coaching were effective at reducing client procrastination and facilitating goal attainment, clients who participated in individual coaching saw a higher degree of satisfaction and attainment of their goals. It was also learned that asking individuals to perform exercises without support from coaches is not sufficient.

These findings highlight two needs for coaches where advances in technology can easily fill the gaps. The first is a need for individualized programs. People who train individually have a high degree of satisfaction and saw better results attaining their goals than people training in groups [10]. Technology now allows for athletes to send individualized programs to clients around the globe entailing full exercise descriptions, pictures, and/or videos. This advancement allows clients to quickly and easily swap out the appropriate exercises for clients without spending time repeatedly writing descriptions for each exercise. This same process provides clients with the individualized programs they need to achieve the benefits mentioned in Losch et al.'s study.

The second benefit of technological advances in connected coaching is the ability for trainers to maintain the same level of income from group sessions, while providing the attention of individual sessions. Group training sessions appeal to trainers under the premise that a trainer can get more clients into a session because the rates are lowered and make as much money if not more than during individual sessions. This principle follows basic supply and demand. The more clients a coach can train in an hour, the lower the rate for each client. Using advances in technology, trainers can implement customized exercise regimens for their clients using workout building programs which allows trainers to save programing time and thus get their programs out to a larger group of people as they do during group training.

The coaching world is making a shift, and strategic adoption of advances in technology allowing coaches to reach more clients on a personal level will open revenue streams for trainers by expanding their reach, improving client retention, and personalizing exercise programs. Trainers whom adopt this approach to technology earliest, will place themselves in a strategic position for increased revenue.

2. The benefit of applying technological advantages to sport, fitness, and health

According to Jones [11], "It is based on the notion that at the heart of coaching lies the teaching and learning interface, and the myriad ways through which coaches influence athletes to develop and improve." This teaching and learning interface can come in many forms. How a coach and their athletes engage in their lessons will vary depending on the sport, coach, and individual athlete. Regardless, according to Dudley et al. [12], the most important elements of coaching are: supportive leadership, effective communication, open-mindedness,

and the ability to be empathetic. These four characteristics help coaches identify client problems and provide solutions to those problems as well as establish trust in their relationship. These attributes have remained constant in their essence throughout the centuries. With that said, the interface through which this relationship takes place has changed during that same time. From a purely verbal face-to face communication of knowledge and experience during times when written documentation was scarce, to the introduction of the printing press which allowed coaches to share knowledge they have written for numerous athletes for study and intervention. Even in the age of the personal computer, tablet, and smartphone that we live in now, this style of coaching, providing athletes with face-to-face coaching as well as written programs they can perform on their own time is the current model of online coaching. With that said, this unidimensional model is the foundation of the technology currently available to coaches. It is a dated static approach operating in a new dynamic system.

Technology has progressed to a level where it can effectively be used as an arm of coaching, extending the reach beyond what coaches are currently providing their athletes, yet coaches are providing static documents, PDFs, and drag and drop workouts in a unidimensional system. Currently, there is very little feedback provided to the coaches. A new dynamic approach to coaching, employing the same communication channels people positively respond to on other social networks, combined with the growing use of activity trackers such as Garmin, Fitbit, and Apple Watch, allows coaches to gain access to real-time results from their clients. Coaches are now able to provide online programing to their clients and receive data allowing them to adjust programs as necessary. Activity tracker feedback offers coaches an honest feedback mechanism and open communication without hindering clients. Clients simply wear their activity tracker and coaches monitor client progress in the background. Coaches can finally take a once static exchange of information delivered as a snapshot in time (a one-hour workout program) and incorporate 24 hours per day feedback from activity trackers, making programs dynamic and alive.

Applying technology in sport in this manner allows coaches to bring their exercise programs to life. One company, iGetBetter Wellness takes the concept a step further by allowing coaches to establish thresholds for their clients so coaches are only alerted to check on a client when a threshold is violated. Otherwise, the coach and client can step-back and allow the program to progress without interruption. This concept allows coaches to monitor and train a much greater number of clients at a higher standard of care. In essence, athletes constantly have coaches monitoring their progress, but coaches are not constantly bombarded with alerts because thresholds set by the coach act as gatekeepers for when coaches receive information from clients. If coaches want to automate their feedback, they can send automatic responses for specific threshold violations [13].

In my book How to Improve at Fitness and Beat the Competition: Sport and Exercise Science for athletes in Search of Excellence [14], I make the following statement,

> *"Society has redefined American culture focusing on time efficiency as well as maximizing value within that given time. With that said, medicine, science, and technology are collaborating to bring attention to America's growing health concerns. With medicine and science discovering what needs to be done to improve American health and technology implementing new techniques of engaging people to improve*

their health. This hybrid between fields is the perfect opportunity to convince busy people to begin implementing relatively non-time-consuming exercise programs such as the ones justified in the above research into their lives, prolonging life as well as increasing its quality – athletes should use new technologies to monitor their health."

The sport industry is participating in a world where people have ever-growing circles of concern needing their attention. These concerns should be prioritized and streamlined to effectively incorporate time for effective sport intervention. Technological advances allow for such priorities to take place. An example of this are activity trackers reminding individuals to stand throughout the day without putting thought into it. People simply set a reminder to stand up and walk around their office or home every set period then wait for the alert to remind them to move [15]. Technology such as this allows people to focus on their career, education, or family while still getting in the activity they need to live healthy lives.

2.1. Social networks and positive behavior

In 2014, Maher et al. [16] conducted research regarding social networks and health behavior change. The team of researchers compared 10 studies to determine if social networks are beneficial health behavior interventions. Their results concluded that there are significant benefits associated with positive behavior change from social network intervention. Coaches who are aware of such interventions and are willing to engage with athletes on social networks can be successful in two ways. First is through the positive behavior changes mentioned in Meher and collogues study. The second is through the social presence and social media exposure that will naturally occur from working with clients on a social network. People on social networks like and share high arousal post that spark positive emotions [17]. When many people share high-arousal positive-emotion post, it makes post go viral which is great for business exposure. When a coach's athletes do this, it acts as free marketing for the coach. This free marketing exposure extends the coaches brand to new prospects and provides the coach an opportunity to grow their coaching business.

2.2. Client retention

The coach and athlete relationship exist in numerous circumstances. The two most basic types are the traditional coach of a team and the coach of an individual. Coaches of teams attain clients from an array of methods depending on the context. For professional teams it is through sports agents and player contract negotiations and for high school teams it is generally based upon the athlete's location for public school and the school's reputation for private schools.

When it comes to coaches working with individual athletes in a private business setting such as a gym, the relationship may change. This is especially true if the coach is acting as a business owner or independent contractor for a private coaching company. In this role, the coach is now acting as a service provider for hire and is in constant worry the athlete may leave them. It is 5–25% easier for a service provider to maintain a client than to find a new client [18]. It is also suggested that increasing customer retention rates by 5% increases profits by 25–95% [19]. These statements make it clear that special attention must be placed on client retention. One method for increasing client retention is gamification. Gamification

has been proven to be especially effective at attracting, engaging, and retaining athletes [20]. Gamification is the process of applying game-based mechanics or attributes of a card, board, or videogame to another field in order to increase usage. Game-based mechanics take many shapes, often unrecognizable as a game. Many social networks utilize gamification without you knowing [21].

2.3. Just how accurate are activity trackers?

Perhaps the greatest technological advancement in activity tracking is wrist-worn activity monitors used to measure a variety of features including but not limited to steps, sleep, stress, and heart rate. The data these activity trackers gather can then be sent to a phone app, website, or other device. It seems every day an additional co-worker enters the building swapping their traditional watch or replacing formally bare wrist with a smart-watch. With that said, watches are only the beginning of wearable activity trackers. Some companies are in the process of developing wearable technology that can be worn on a necklace, bra, in a shoe, or other locations [22]. What we are seeing now is only the beginning of activity tracking and sport motion monitoring. There is no reason activity trackers cannot be placed on lacrosse sticks or soccer balls to measure velocity, running shoes to measure impact and pace, or a basketball to track the number of shots taken in an hour. Information such as this adds valuable data points to a coach's exercise programing abilities. One way of looking at these additional data points is thinking of them as additional time athletes are spending under the supervision of their coach. If a tennis player's racquet is capable of tracking a pre-set swing for a given athlete that data can be sent back from dozens of athletes at once, which would otherwise prove impossible for a single coach to effectively get eyes on every player in the same period [23]. This would allow coaches to focus their time on an athlete's other areas of concern (**Figures 1–4**).

All of this tracking sounds great; however, the technology is still relatively new. While research has shown consumer-level activity trackers to be valid for the measurement of many daily activities, there is still room for improvements [22]. Most activity tracker improvements are taking place first in the medical field. The medical field's highly regulated environment operates at a high standard due to the risk involved with using lower-grade technology [24]. As better technology is invented for medicine, these inventions and innovations will benefit sports, health, and wellness. This concept provides reason for sport coaches to have insight in medical coaching practices.

2.4. A smooth transition from medicine to sport

Medicine and sport exist on the same health spectrum. Traditionally, medicine has been used as a reactive treatment for individuals seeking aid after experiencing troubles affecting daily life. Whereas, sport is catered more towards increasing activity levels and/or human performance, with hopes that an active lifestyle will improve quality of life resulting in less future medical intervention. A 2014 article published by Harvard Health Publishing, a part of Harvard Medical School explains how the more exercise an individual gets, the healthier they will be, as long as they do not become injured from the process. As little as 15 min of moderate activity such as brisk walking was shown to make a difference in health [25]. This slight increase in activity can make people healthier and reduce the incurrence of medical intervention.

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Figure 1. Garmin app user profile screenshot.

Health and wellness is also employed after medical treatment ceases and patients are seeking additional guidance. There is a need for multidisciplinary teams to improve clients' wellness and improve health upon completion of medical intervention. With that said, there are companies aiming at connecting the two points on the spectrum. iGetBetter, is a pre- and post-medical treatment company providing a platform for clinicians to prepare and monitor orthopedic and cardiovascular patients before and after surgery in order to increase their success and recovery rate. iGetBetter is taking a preventative and post-rehabilitation approach more commonly seen in health and wellness and applying it to medicine [26]. Moreover, they are now blending what has been shown to be a successful intervention in medicine into health and wellness resort spas through the application of sport. They have come full circle, employing the same strategic mindset of Colonel John Boyd mentioned earlier by taking a health and wellness mindset and sharing it in a medical setting then using their medical-grade platform in a health and wellness setting, but with medical-grade patient security and

Figure 2. Garmin performance statistics.

Figure 3. Garmin health statistics.

activity monitoring. What is being created using health, wellness, and sport ideologies for medical intervention is being adapted back to health, wellness, and sport while maintaining its high medical quality standard.

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Figure 4. Garmin insights page.

2.5. Leadership in medicine involves coaching

The high standards and prestige associated with being a medical professional is the result of years of high quality medical training. This training is available in a variety of formats, however, a study by McNamara et al. [27] concluded clinical leadership development programs include mentoring, coaching, and action-oriented learning interventions. This is of significance because it shows a need for medical professionals to receive coaching which can be provided through social platforms. Medical professionals currently share opinions and advice through annotations or behind the scene notes that the patient generally does not see. This ability opens up a communication channel for medical professionals to advice and coach each other on a particular patient. Medical doctors can share insights into a patient's progress and coach each other to the best solution using a holistic approach of everyone involved with the patient's medical well-being.

Now imagine if an athlete's fitness trainer, skills coach, and dietician could all communicate and share insight in the same manner as medical professionals (**Figures 5–7**). This approach is part of the medical technology iGetBetter Wellness is bringing to sports professionals [13].

2.6. As a means of culture change

Thorn and Raj in their article *A Culture of Coaching: Achieving Peak Performance of Individuals and Teams in Academic Health Centers* [28], suggest that currently in medical academia there is a lack of focus on the "being" aspect of practicing medicine. Medical students should spend more time learning how to be a coach, listening to client stories and painting positive relational perceptions of their patients. The authors recommend integrating professional coaches and teaching faculty how to develop coach like behaviors that will aid in this culture shift. Their findings suggest faculty who are already employing such techniques are seeing a significant enhancement in board pass rates, an increase in both faculty and resident perceptions

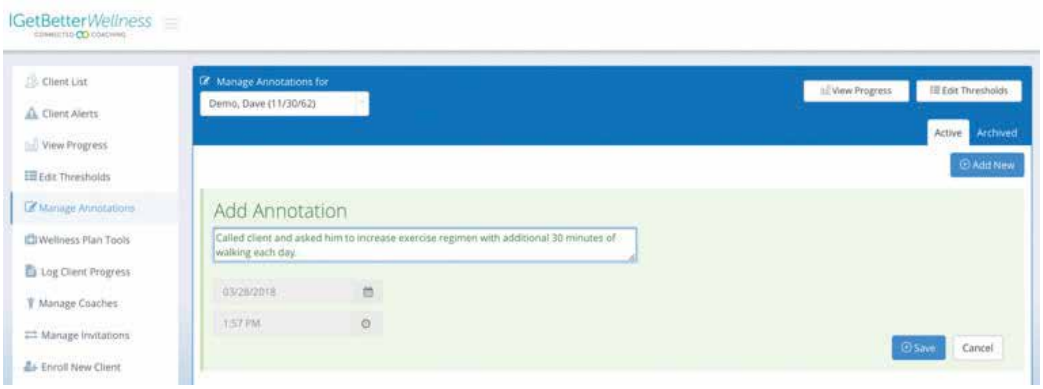

Figure 5. Medical doctor saving an annotation to a client's profile.

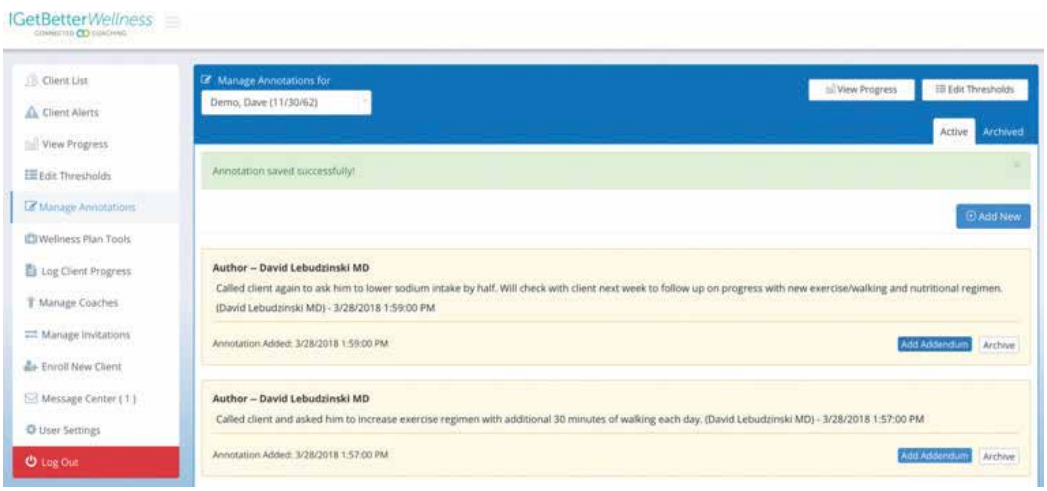

Figure 6. Annotation after the doctor successfully saves the note.

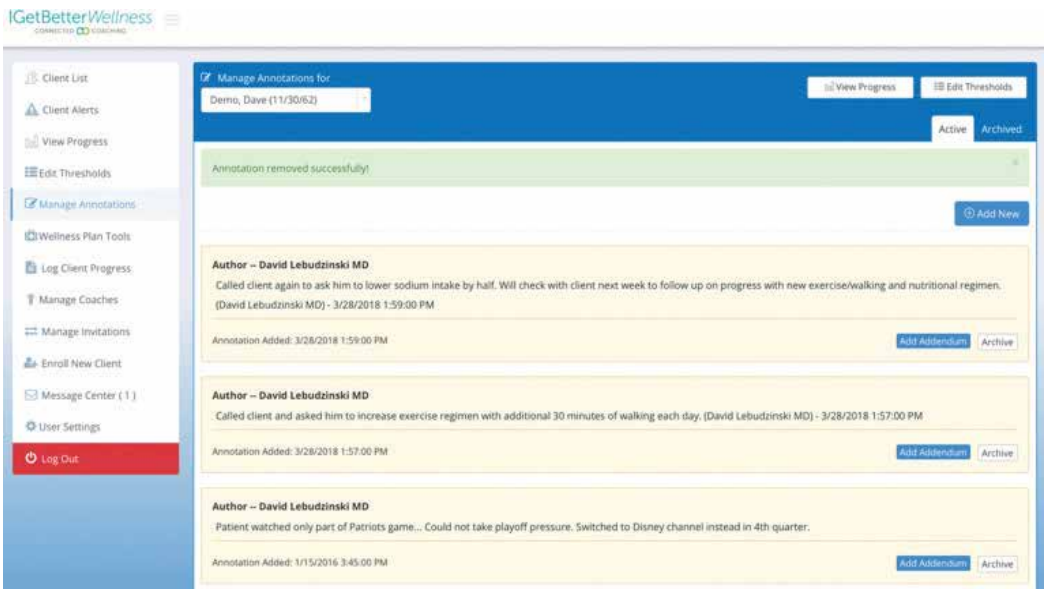

Figure 7. Stream of saved notes by the doctor.

of residents' lifelong learning ability, and a discernable confidence in resident mindsets. The anecdotal evidence also reported enhanced trust in collegial relationships and a surprise in the positive change in their attitudes.

The need for coaches as intermediaries in medical school is an opportunity for open source teaching platforms such as Moodle and Canvas to allow coaches to extend the reach of their services. Every year, online teaching and training is becoming more prevalent and accepted in academia as evident by the increase in schools providing online education [29]. This creates a perfect opportunity for coaches to benefit from this trend. Just as sports professionals can learn from medical professionals, this is an ideal opportunity for coaches to share their interpersonal skills and healthy and active demographic experience with medical doctors.

3. Conclusions

In closing, there is ample evidence that technological coaching advances are leading to improved client sport performance, health, and retention. Just as technology has always been an underlying theme in humanities progress, from the agricultural revolution 12,000 years ago when people began using tools to domesticate plants and animals, to the global food operations we conduct today. Coaching has been present and evolving throughout history, shifting form as technology advances yet always maintaining its underlying theme of helping others improve. The application of new technology in the coaching process is nothing new, just the next chapter in our story. What is new, is how coaches involve modern technology while providing multidisciplinary teams to improve clients' wellness and improve health. Never before have coaches had such an expansive

influence over their athletes. This reach provides a challenge for coaches to find the method for them that best takes advantages of the dynamic and integrated coaching experience occurring today.

Conflict of interest

The author of this work is a contractor for iGetBetter Wellness Inc., which is one of the examples used in the research.

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Chapter 4

The Application of Sports Technology and Sports Data for Commercial Purposes

Kenneth Cortsen and Daniel A. Rascher

Additional information is available at the end of the chapter

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Abstract

Contemporary professional football (and sports) entities have embraced technology and data to boost sporting quality. However, this development has gone beyond the playing field as technology and data also start to play a larger role in improving business performances in the football (sports) industry. This chapter looks into how technology and data in the form of sports tracking systems, cf. based on (but not totally limited to) the case of the ZXY sports tracking system, are capable of helping to translate improved sporting performances into enhanced business performances. The intensified commercialization in football from technology and data takes fandom to new heights and bring about new revenue generating opportunities. However, harnessing the increased amounts of data is associated with technical challenges and financial and human resource constraints. In some instances, the context of applying 'big data' in football is still premature. Therefore, the technology and data implementation in professional football needs to undergo a qualification process to secure that the applied data co-exists with a context of competent knowledge-sharing, individual and organizational learning in order to positively develop sporting and business performances.

Keywords: football, soccer, big data, commercialization, technology, sporting performance, business of sports, fandom, sponsorship, sport experiences

1. Introduction

Sports technology and sports data have become integral parts of sports development and performances [1–4]. As seen in relation to how technology and data play a role in improving player development and sporting performances, the business side of sports has also embraced the upsides of technology and data analytics [5]. The purpose of this research is to study the

application of sports technology and sports data from the 'sporting side of sports', e.g., data from sports tracking systems. In doing so, focus is primarily on football (soccer in the US) but the study also integrates relevant perspectives from this context associated with other sports. In addition to 'the sport of sports', the study discusses how sports technology and sports data act as a commercial vehicle, which can guide and drive content production for a sports property's commercial stakeholders in the 'business side of sports', e.g., fans, sponsors and the media.

2. Methodology

This chapter is based on case study methodology [6–11], in which the case of the ZXY sports tracking system is the focal point. The chapter also includes data regarding other tracking systems than ZXY for a broader discussion and understanding of the context of sports tracking and how that influences sports, e.g., sporting and business aspects. The chapter involves critical methodological reflections and takes the commercialization and professionalization of the football economy into consideration as vital contextual factors, i.e., incorporating the application of technology and data in relation to sporting performance as well as business performance in professional football (sports). The case study applies an in-depth qualitative approach, which encompasses the dynamic context in which sporting actions and experiences take place [12]. Hence, research cannot be isolated from time and context [13]. The relevance of the case study is grounded in the methodology and its qualitative nature, i.e., based on two semi-structured focus groups and one semi-structured face-to-face interview. The qualitative foundation bridges a knowledge gap in sport management research as this case study goes beyond the explanation of statistics to investigate and understand a dynamic sports context at a time where technology and data are on the rise.

2.1. Case description

The ZXY sports tracking system was originally developed in Norway by ZXY Sport Tracking AS. The system went through a development process in collaboration with Norwegian Olympic Sport, the Norwegian top football club Rosenborg Ballklub and Radionor Communications. The method to develop the data measurement has its roots in technology linked to military radio signals [14]. The first generation of the system was released in 2007 and tested by the collaborative partners. The second generation of the system saw its release in 2012 in relation to a project with the Dutch football powerhouse Ajax Amsterdam. In 2014, the Danish top club FC Midtjylland, which is known around the international football landscape for its strategic data analytics approach [15, 16], invested highly in the ZXY system in order to enhance its sporting decision-making processes [17] and thus to elevate the quality of the club's cohesion between sporting and business performances.

In 2014, the American corporation ChyronHego bought ZXY. ChyronHego works on a global scale on broadcast graphics creation, playout and real-time data visualization [18] and found increased opportunities to develop a stronger and more applicable product by combining ZXY's very precise[1] sets of data with ChyronHego's existing tracking system Tracab. The latter already

[1]According to ChyronHego, ZXY provides coaches and sports scientists with *"the most accurate and repeatable set of performance metrics for any type of Electronic Performance and Tracking System (EPTS) on the market"* [19].

functioned as an established part of many football clubs and leagues. In practice, the ZXY solution works by players carrying a belt around their waistline, e.g., incorporated in their shorts. The belt is ultra-light to show regard to the players' functionality. The system incorporated in the belt sends data to the radio receivers, which are installed in the venue or at the training facility (as the system is functional for game as well as training situations). The quality of the data transmission is enhanced by the fact that data transmission takes place 20 times per second[2]. The data pool becomes available through the operation of ZXY's software, which is accessible via an online web site or an app designed specifically to process and present the data (**Photo 1**).

The user experience is adaptable by allowing physical trainers or other specialist staff at clubs, leagues and federations to determine what to measure and how to apply and present the measurements. Additionally, the system is able to incorporate the use of video cameras to increase the focus on players. Personalized video measurements provide data synchronized in time from body sensors combined with position sensors in the venue or at the training facility. The following are examples of data provided (**Figure 1**):

- Positional updates at least 20 times per second (=20 Hz).
- Distance in relation to different types of movement, e.g., jogging, ordinary running, high intensity running, or sprinting.
- Acceleration vs. deceleration.
- Performance index, e.g., total vs. under acceleration or deceleration.
- Frequency of steps.
- Speed of turning.
- What direction does the player face (e.g., heading).
- Run characteristics (offensive or defensive).
- Heart rate.

Photo 1. An illustration of the ZXY sports tracking system installed at a football stadium [14].

[2]The ZXY Arena system can be configured to operate with different report rates. The most used is 20 Hz but a 100 Hz setting is also available. Each transponder can be configured independently and dynamically over the wireless control link, which means that if it is raised to special requirements to have a high-resolution sampling, the system user can assign 100 Hz to this user(s).

Play creation Won passes Lost passes Long passes Short passes Dribbling Assists Crosses	**Ball possession** Won dribbling Lost dribbling	**Defensive actions** Won tackles Lost tackles Blocked shots Blocked crosses Blocked passes Clearances Ball recoveries
Strategy plays Corners 'Short' Corners Side fouls Direct free kick Direct free kick to goal Won Throw-ins Lost Throw-ins	**Shots** Goals Shots to goal Shots out of goal Shots blocked Head shots to goal Head shots out of goal	**Goalkeepers** Saved balls Punches Non-blocked balls Won keeper sweeper Lost keeper sweeper

Figure 1. Examples of measurement functions of Tracab as a position sensor system.

Figure 2 below illustrates the added value and functionality from combining Tracab's position sensor system and ZXY's body sensor system. The combination of the two technologies helps to automate Tracab as the ZXY system constantly and precisely knows the position of the player on the playing field.

Figure 2. Value creation from combining Tracab and ZXY technologies [14].

2.2. Research design and data collection

A qualitative methodology was selected as the most applicable practice to explore the experiences and understanding of the meaning related to technology and data in sport [20, 21]. The chosen data collection method is 'interviewing' in the form of two semi-structured focus groups and one semi-structured face-to-face interview.

In validating the results of the interviews, it is essential to critically reflect over the fact that it may be challenging to 'generalize' the findings of a case study in a larger sport management context [22]. Nevertheless, the purposively selected sampling process [23, 24] in this instrumental case study[3] is chosen to enhance the context-specific validity of the findings and thus to expand the interest for and application of the results within the context of technology and data in sports beyond the case of ZXY. However, the intention of this research is to emphasize a paradigm shift in research methodology, which stresses the shift from 'generalization' to 'contextualization' under the premises that knowledge is heterogeneous and contextual rather than universal or individually unique [22]. Therefore, the metatheoretical nature of this research takes a stance associated with scientific traditions from pragmatism [25] and symbolic interactionism [26, 27] to explore the experiences, thoughts and meanings of the respondents regarding the application of technology and data in a context of sports and in particular football. The purposive selection of respondents is influenced by the reasoning that these respondents have complementary competences while possessing relevant and applicable contextual, professional and/or educational experience from the football industry.

The respondents from focus group 1 are listed below (anonymous) in **Table 1**.

The respondents from focus group 2 are listed below (anonymous) in **Table 2**.

The respondent from the semi-structured face-to-face interview is listed below (not anonymous) in **Table 3**.

The qualitative design of this research provides insights from experienced industry professionals in the form of their experiences from utilizing technology and data to improve sporting performances and to enhance commercialization in football. This supports the chapter's production of relevant meaning and realm of understanding in order to inductively construct new suggestions for how to advance and boost the application of technology and data in the form of sports tracking to improve sporting and business performance in football. So, the aim is to let the data speak for themselves, but to do so while systematically, critically and contextually analyzing and interpreting the data. Grounded theory and qualitative open coding are used to analyze the transcribed interview data based on analysis, study, comparison, conceptualization, and categorization of the data [22, 28]. The two focus group interviews were completed in the same venue to accommodate a constructive interaction between all respondents, which is significant for new idea generation and to illustrate meanings and experiences of respondents. The interpretivist research paradigm emphasizes the importance that the coding and data analysis is grounded in context-relevant literature, theories, knowledge

[3]The instrumental case study reflects the purpose of gaining more insights in the general question of how applying technology and data based on tracking systems in sports can enhance sporting and business performances in the context of sports [22].

Gender of respondent	Occupation of respondent
Respondent 1a: Male	Marketing Manager, professional football club with domestic championship and FA Cup titles, including participation in UEFA Champions League and UEFA Europa League competitions
Respondent 1b: Male	CEO, sponsorship agency
Respondent 1c: Male	Venue Data Coordinator, UEFA
Respondent 1d: Female	Commercial Director, national football association
Respondent 1e: Male	CEO & Founder, betting company and football media platforms

Table 1. Overview of the respondents from focus group 1.

Gender of respondent	Occupation of respondent
Respondent 2a: Male	Digital Manager, professional football league
Respondent 2b: Male	Lawyer & Head of Research, fantasy sports platform
Respondent 2c: Male	Partner, sports marketing, branding and communication agency
Respondent 2d: Male	Sociologist, university and IT sector
Respondent 2e: Male	Digital Manager, national football association
Respondent 2f: Male	CEO, investment company

Table 2. Overview of the respondents from focus group 2.

Name and gender of respondent	Occupation of respondent
William Spearman, Male	Currently the Lead Data Scientist, Liverpool FC and former occupation as Senior Data Scientist, Hudl (a technology and data company specialized in sports performance analysis in sport). Spearman specializes in using tracking data in football to understand passing, open space and scoring opportunities. After completing a Ph.D. from Harvard University in physics and inspired by working with tracking data from the English Premier League, Spearman developed a pitch control model, which was presented at the 2016 Opta Pro Forum.

Table 3. Overview of respondent from the semi-structured face-to-face interview.

and professional experiences and competences. The intent is to create a knowledge-producing process associated with the capability to contextualize and recontextualize a context of technology and data application concerning sporting and business performance improvements in professional football (and other sports). In that regard, the chapter's discussions are influenced and guided by the methodological stance and the empirical data. Therefore, the discussions are not covering the application of technology and data from a holistic angle; this is a reflection

of the fact that many different metrics drive decision-making in football. For instance, there is a difference between the tradeoff between a risky pass versus the consequences of losing possession versus the potential benefit of a scoring chance that may be created just to mention a few focal points from decision- makers in the world of football. The point in this chapter is to illustrate that the use of technology and data may improve on-field performance assessment in football (and sports) and this may also have positive spill-over effects on the sport organization's business performance.

3. Setting the stage: connecting sport, business, data and technology

Today, professional sports are characterized by the search for new paths concerning how an athlete or a team may apply new technologies and sports performance data to gain the cutting-edge competitive ability that will elevate them to the top of the podium or to win major league or championship titles [29–31]. Therefore, professional sports properties are left with massive data pools that (without giving away competitive sporting advantages) can be utilized to assist athletes and teams in monetizing on their relationships with commercial stakeholders. In reflections over why the application of technology and data is important in sports, there are clear benefits in terms of optimizing decision-making processes on and off the playing field and thus sporting quality. William Spearman notes that *"It's been a way for intelligent teams to gain a competitive advantage to be able to use perhaps less money, less resources but still have a competitive team."*

There is no doubt that the application of technology and data is beneficial in professional sports. Kerr and Gladden [32] argue that connected technological environments to some extent provide an open-source approach for sports teams to interact with their stakeholders. For instance, this may take place via mobile apps of the teams as suggested by Watkins and Lewis [33]. Reasons to go in that direction are clear. One practical example is the current Danish football champions FC Midtjylland that invested in an app solution in 2017 to boost engagement with fans. The idea was to bring fans closer to the club and to produce good fan experiences by providing fans with exclusive news and better insights about the players and their performances. The financial situation of professional sports teams is boosted by good sporting performances. Better sporting performances may be supported by technology and data and can help to enhance the entire business model and the backing from fans and other stakeholders in relation to revenue generation from various sources [34], e.g., ticket sales, broadcasting contracts, merchandise sales, good sponsorship activation and the increased value of fan engaging content production. Couvelaere and Richelieu [35] consider the importance of sports teams engaging themselves in a way that is synergistic with the lives of their fans in order to bring the brand of the team to life by letting fans live it. Now, years have passed since the publication of their scientific article. Therefore, it serves a purpose to acknowledge the growing weight of technology and data on people's lives and in sports [33], which provides a good grounding for putting additional focus on this intersection as highly identified fans show likeliness to engage with teams, athletes, and other sporting stakeholders via online and digital platforms to gain more in-depth information [36].

4. Sporting performance

Technology and data have become manifested elements of professional sports in the hunt for enhanced and elevated performance platforms. Additionally, their application reaches beyond that of professional sports and even targets fans and consumers outside the spotlighted playing fields in professional sports. In the aftermath of this development, actors in the professional sports industry underline the importance of technology and data as being directly associated with winning titles. However, the vital role of technology and data in influencing sporting performances is clear but there is reasonable meaning in acknowledging that technology and data are only tools and not a universal quick fix to performance challenges in professional sports. Consequently, technology and data do not solve cultural problem areas in sports. For instance, such complexity is apparent in the management of professional team sports and one may similarly argue that the same difficulties exist in professional individual sports, e.g., tennis or golf, in which the professional athletes are supported by an entire team of physical therapists, coaches, fitness trainers, etc. Yet, the point of this discussion is that technology and data may support decision-making although not being the solution in their isolated capability. Spearman notes that *"So with MLB baseball or basketball, it's been a way for intelligent teams to gain a competitive advantage to be able to use perhaps less money, less resources but still have a competitive team that performs at a level that either supersedes their talent level or perhaps even changes the game a bit in terms of prioritizing maybe certain skill sets that are currently undervalued but can be used as much as another skill set that might cost more when trading for or transferring for a player or paying a player."* Managing performances on the sporting field or in the business of sports is a dynamic and complex phenomenon. Spearman's comment highlights the additional complexity, which is evident in and between the two spheres of sports, i.e., sporting and business performances. The cohesion was portrayed in Michael Lewis' book *Moneyball—The Art of Winning an Unfair Game* about how the *Oakland A*'s MLB baseball team utilized systematic data in the form of 'qualified' statistics, e.g., 'sabermetrics' and thus scientific methodology, to gain competitive advantage in managing the team's sporting performances and thus also managing and influencing its business performances. In the book, Lewis cites the team's General Manager Billy Beane: *"There was no simple way to approach the problem that Billy Beane was trying to solve. It read like an extra credit question on an algebra quiz: You have $40 million to spend on twenty-five baseball players. Your opponent has already spent $126 million on its own twenty-five players, and holds perhaps another $100 million in reserve. What do you do with your forty million to avoid humiliating defeat? 'What you don't do,' said Billy, 'is what the Yankees do. If we do what the Yankees do, we lose every time because they're doing it with three times more money than we are.' A poor team couldn't afford to go out shopping for big league stars in the prime of their careers. It couldn't even afford to go out and buy averagely priced players."* ([37], p. 119). As pointed out, sports organizations may benefit from theoretical grounding and scientific methods to understand and influence sporting performances positively and thus to enhance business performance as a derived effect. For instance, the transfer of players is a function of this in that it provides positive or negative transformation on the sport organization's on- and off-field performances [38]. So, science and knowledge create the platform for understanding

but as demonstrated in the 'Moneyball' example and by Blumer [27], p. 143, *"Theory is of value in empirical science only to the extent to which it connects fruitfully with the empirical world."*

This illustrates the value of technology and data in lifting sporting performances, but with the hint that sporting tracking and positional data must be 'qualified' to be applied intelligently and effectively in order to positively reinforce sporting performances in practice. For instance, it holds essential meaning that the application of technology and data is based on a solid understanding of the interplay between various contextual factors and the importance of timing when executing performance-based decisions, e.g., the technical and tactical capabilities of the individual players in contrast to the team's tactical game plan, the strength and weaknesses of the opponent or the fact that the coach has only a short window to receive, interpret and execute on data during the game. It is imperative to have a platform of knowledge before decisions are made. This knowledge is often mixed with intuition and passion, e.g., from a coach, in reality in professional sports, which helps to determine the perception of decision-making and therefore adds an extra complexity level in dealing with the intersection between technology, data and sports.

From a critical perspective, the quality of the application of technology and data in professional sports is also subject to bias as there is always a person behind the data. Therefore, applying technology and data may sometimes risk being subject to what Vamplew [39] coins as 'reverse research' in which sport organizations know the desired conclusions beforehand and aim for evidence that will back these conclusions or look to apply conclusions that are not fully backed by the empirical data collection. This may exist when the sport organization applies technology and data to find evidence, which supports predetermined conclusions about a given athlete, who hypothetically underperforms on specific parameters. It may be associated with predetermined conclusions that there are lazy players on the roster for what reason it becomes a way to punish all players with a salary cut. This is a risky management path in sports, which is associated with a negative 'documentation culture' and not a sound application of technology and data in sports. Despite this managerial complexity, the application of technology and data adds value to sporting performances in team sports, e.g., football, by offering tracking opportunities concerning the positioning of the athletes and how that changes dynamically in the game and how that affects the possibility of scoring or improving one's team position over another. This inspires the potential to optimize sporting performances via positive influence on the sporting quality, on the outcome of the game, and the associated learning.

Managing sporting performance through the application of technology and data also stresses the significance of differences between sports. For example, the sport of football is a complex sport. One may argue that it is more complex than some other team sports, e.g., basketball, or definitely more complex than many individual sports, e.g., golf and tennis, as the game of football is characterized by having 11 players on the pitch and rules like offside. This means that the players are not necessarily close to the goal for what reason decision-makers on and off the pitch have to figure out how to get into situations with the opportunity to score. That is different in other team sports such as basketball, baseball or team handball. In football, all of the players except for the goalkeeper have to do all the skills, unlike American baseball, where an outfielder does not really handle ground balls that are moving quickly. Basketball

has become more like football in that even big men are expected to be better dribblers, passers, etc. Spearman admitted that football *"is a much more complicated game especially than baseball and even basketball, which has seen a lot of success with data […] You've got 11 players versus 5. You've got a pitch, which is much, much larger. You have so many more phases of play."* Phases of play refer to transitions, buildup play, working into the penalty area just to mention a few. Spearman adds *"That's maybe why there hasn't been kind of this sort of public awareness breakthrough concept that's really impacted the game in the way that you've seen in basketball with 'WAR'*[4] *and baseball with pitch framing and you know sabermetrics and some of these simple statistics that changed that in a big way."*

5. Improving sporting performance needs the right framing

The complexity of some sports over others, e.g., football over basketball and baseball, does not mean that there are no opportunities but merely more work to be done in qualifying the data. There are also more naturally occurring statistics in basketball such as field goal percentage, rebounds, steals, etc., that are more difficult to generate or track in football. Basketball is now tracking passing in a way similar to how football does, which looks at how the pass improves the situation on the field (not just whether it was received or struck cleanly). Moreover, it means that there is a lot of potential for technology and data since there are many opportunities that have yet to be fulfilled. The world of football has not seen the full implementation nor value of investments in technology and 'big data'.

The points regarding football is rooted in the debates, discussions, decisions (also for qualified application in professional clubs) and consumption[5] of the sport. However, technology and data applicants with a deeper understanding of the game know it is fine to run a lot, e.g., football is a 'running game' (legs feed the wolf), but they also know that it is not about the quantity! The quantity must be 'qualified' in the sense that football is about tactical positioning. Therefore, players should run intelligently. It helps to be fast in football but not if you run out of the stadium with the ball. Spearman supplements in that technology and data should be applied in helping players to strive to avoid an action if *"it doesn't help your team at all."* He adds that *"A lot of this comes into, you know, there are numbers, which mean nothing. And so, for a number to mean something you have to correlate it. And to correlate it in a proper kind of way, you have to build a model and the best models out there use Bayesian inference*[6]*."* With this in mind, working with 'big data' is not sufficient. The big challenge for sport organizations is to incorporate the data to a more qualified extent on and off the playing field. It can be done by raising the expectations for the positive outcome of working with technology and data by qualifying data via further sophistication and holistic analysis in the form of data correlations.

[4]WAR is a synonym for 'wins above replacement' and articulates how many wins a player provides to a team's accomplishments related to the likely number of wins the same team would have accomplished with a replacement [40, 41].

[5]When one watches UEFA Champions League games on television, it is portrayed that Cristiano Ronaldo or Lionel Messi have run a specific distance, have a certain percentage of successful passes or have had a specific maximum speed during the game.

[6]Bayesian inference is a scientific statistical inference method, which applies probability updates regarding a hypothesis in alignment with the availability of information. The method's focus on updates considers the active breakdown of series of data, so as new information is available, it updates the model.

Spearman stresses that a good model *"very closely mimics the way the human brain works, which is, with my experience, I found these correlations with certain probabilities […] Like my mind, when I see you know like a car driving down the street. In my mind, I build a Bayesian model and I'm like OK 99.9% of the time this car is not going to crash but maybe 0.1% of the time it might crash into something because of user error or something like this. So, I have a set of outcomes that I expect whenever I see something because of my internal mental model."* So, a number in isolated fashion does not tell people anything but when being associated with a specific context and its fundamental contextual factors it makes more sense just like the number 10 makes more sense on the back of Pele's or Maradona's shirt. Thus, working with data and incorporating them into a specific sports context and thereby bringing them to life makes a meaningful difference. Spearman supplements this: *"If I'm watching a football match or a soccer match. My mental model might say that when Manchester City plays Wigan […] I expect maybe a result like 4-0 like maybe 20 times out of 100, I expect a result 5-0 maybe 10 times out of 100, 6-0 5 times out of 100 and I expect like a Wigan 1-0 defeat of Manchester City maybe 1 time out of 100 […] By having that set of possible outcomes I've built this mental model."* Framing in the form of models is a way to give meaning a certain direction, which is necessary in working with data in sports. Spearman says *"The problem is like I have to have that model before you can really say anything. So, like saying a number like: this person ran 14 kilometers, that's just numbers that doesn't tell you anything at all. So, you need to say: like teams that run 14 kilometers have these outcomes or something but because and then the person who's reading that statistic can recognize: well this model only took into account one variable: distance run. That doesn't mean anything."* This influence of technology and data in sports integrates working with and affecting the expectations of the sporting performance while going beyond the playing field. The latter includes becoming a powerful touchpoint for fans watching the game in the stadium, on television or on a second screen and thus getting a richer fan experience, e.g., a better comprehensive experience when the sporting and business performances of the sport organization are blended.

Concerning the sporting performance, technology should not only be a means to collect data to tell a story. The purpose should be to gain a more complete understanding of the sport, e.g., football, and thus how we get in a situation with higher probabilities for scoring or other elements that may increase a team's winning chances. Football is, as mentioned before, a very complicated game in that sense. For instance, data may reveal that there is evidence that the opponent's strong left central defender goes aggressively to cover the area around the first post to defend crosses from the right flank. Combined with tactical understanding, the data stimulates other play solutions than the area around the first post when crossing the ball from the right flank. Vamplew [39] argues that theories or suggestions without validated evidence just function as competing hypotheses. This means that they may assist our understanding but cannot entirely explain the dynamics of a context. It is complicated to guide sport organizations to apply technology and data as there are many elements to be studied; this is especially true in complex sports like football. Therefore, it serves a purpose to critically discuss counterfactual studies. For instance, football and other sports are contexts filled with clichés, e.g., if he/she had been fast, he/she would have become a professional football player or if Denmark did not have Christian Eriksen on their Men's National football Team, they would not have qualified for the 2018 FIFA World Cup. From a critical stance, one can definitely discuss the validity of studying such hypotheses.

6. Qualifying data

The 'quantifiable' element is applicable in the 'sport of sports' and in 'the business of sports'. However, it should be 'qualified' to be applied in an effective manner in practice. The guiding premise of this chapter is that one effective roadmap for understanding sporting and business performances in professional football is associated with technology and data. The bridges between new and existing knowledge that are produced within this intersection can be a reinforcing force for future performance levels. So, this chapter will discuss specific approaches to how technology and data in sports can help to facilitate improved sporting and business opportunities in professional sports.

In this context, tracking systems may help to understand the positioning of the athletes in football and how that affects one's team groundwork to win the game. Qualifying data is vital in that process. The distance covered in a game cannot stand alone and neither can data about a player's change of direction, the intensity of his/her running, moments when he/she stands still (it may happen because the flow of the game is one-sided) or the areas in which he/she moves. In qualifying the performance data, it makes sense to critically assess the tracking system and thereby how the pool of 'big data' is generated, e.g., is the system based on radio receivers (originally the technology of ZXY), GPS (the technology of Tracab) or video cameras (ChyronHego's acquisition of ZXY opens up for a more holistic tracking solution capable of combining the three technologies)? Decision-making in top football is associated with big business and large amounts of money. A wrong decision may be very costly. Therefore, it is imperative to have a valid notion of whether or not a player performs to the level of his/her ability or below or above the expectations before decisions about substituting a player in a game or buying or selling a player on the transfer market is made. Of course, the decision-making process is influenced by complications as performance in football on the pitch is a reflection of a player's opportunities to unfold a combination of physical, tactical, technical and mental elements and putting these in play in co-creation with other players.

Technological advancements have brought even more data to the surface in the context of sport and have influenced the evolution of specific sports. Professional football is one example. Years ago, the prevailing statistic measurement was the amount of goals scored. Along came elements like the number of passes and assists. However, contemporary professional football adopts more sophisticated data and metrics. Spearman emphasizes that *"Now, we're starting to build advanced metrics that kind of take in a few counting metrics and give you another metric like expected goals. Now, with the tracking data, we're not even counting anything we're just measuring where people are and we're using that to come up with new metrics. You know, there is so much that goes into the game […] The data can always be more."* So, the importance of qualifying statistics is a matter of acknowledging that 'big data' cannot do everything for you but it is a basis for including thoughtful sophisticated solutions. With that recognition, the next question becomes a matter of questioning the challenges of technology and data application in specific contexts. Spearman adds that *"With tracking data, you just have the position of the players. You don't have the facing, you don't know what direction they're facing. You don't know which foot they're on. You don't know their weight distribution. You don't know what their mental state is."* Thus, qualification of technology and data is 'training' the skills of finding and working with

the limitations of 'big data'. In following up on this, Spearman admits that *"There are so many things that even this like very, very cool tracking data doesn't measure. […] We're measuring humans. There is no way to finish this. Humans are extremely complicated and you're never going to be able to capture all of that with data but, you can always keep capturing more.* "This is a fascinating discussion as the junction between human beings and (professional) sports continues to find new methods to raise the bar for performance and performance measurement. A good example is linked to a professional research visit to global technology and data powerhouse SAP's corporate headquarters in Germany and an included visit with the affiliated Bundesliga club TSG 1899 Hoffenheim. The club's training facility reflected an innovative football-data-hub with the 'Footbonaut' playing a central role, e.g., a machine that trains a player's technical handling of the ball and his/her response skills. More impressing, the training center offered access to SAP 'Helix', which is a technological solution that trains a player's cognitive skills, e.g., the player's perception of the game in specific game situations [42].

Qualification of data to be applied in football is subject to challenges and downsides. More knowledge about these constraints may guide football entities to construct better interactions between technology implementation, data management and sporting and business performances. For instance, if you take a picture but it is fuzzy, then it is beneficial to apply digital technologies because you get instant feedback. Spearman notes *"There are two advantages I can see coming from Sports Analytics. One of them is the ability to apply the scientific method and overcome your biases. That might be long held biases that come from one reason or another."* Consequently, this scientific approach may prevent football entities from being negatively influenced by 'fundamental attribution errors[7]'. Situational contexts of behavior are a strong influencer in which people when interpreting behaviors or performances of others may tend to overestimate personal elements, e.g., he/she is a very good player, over the impact of the situation, e.g. yes, but he/she did not actually perform well in that concrete situation. The example portrays a common bias that may lead to strategic decision-making being unstrategic decision-making. Spearman illustrates other advantages of qualifying data, i.e., *"You can use the scientific method to overcome, you know, something that's maybe a bias that you might come in with […] The other thing that analytics can do is it can it can be a force multiplier."*

Qualifying data implies the vitality of the interplay or the co-creation[8] between 'human and machine' in the sense that Spearman stresses that *"If you have the best scouts and the best analysts, they are going to be better than even the best models because their mental model takes into account many factors that the data doesn't control for.* However, football governing bodies, leagues and clubs have different resources and resource allocation is a constraint for many clubs in the competitive war for talent. This is in alignment with Spearman's notion that *"You can't have a hundred thousand scouts, who are looking at every player and watching every minute of their film and analyzing it with that domain knowledge. There's just not enough of them in the world and there's not enough really good ones in the world."* This statement reflects the point that (1) data must

[7]The Fundamental attribution error is the *"tendency to focus on the role of personal causes and underestimate the impact of situations on other people's behavior."* ([43], p. 106).

[8]Co-creation in the context of this chapter means a collaborative process between different parties involved in the work with technology and data, e.g. data suppliers, system, data analysts, coaches, players, fans, and sponsors as co-producers, which jointly create mutually beneficial value with the strategic advantages that may be attached [44–46].

be qualified and (2) data cannot replace human beings, e.g., coaches or scouts, but it can be a very helpful tool that leads to positive reinforced performances if managed competently. In terms of data being a football management tool, Spearman mentions that *"If you're a club, you can take that information you have from your scouts. You can use that to train a model, which lets you multiply the number of players you look at or if you're trying to do pre-match analysis for an opponent […] You can't have enough pre-match analysts to watch those all in the detail required. So, again data is a way to let the computer save you time."* Concluding on the qualification angle, data management in football becomes a helpful tool that saves time that may be used elsewhere in the performance cycle of the governing body, league or club. So, qualifying data takes decision-makers from the somewhat automatic and irrational first step of decision-making to a more rational, effective, and strategic second step of decision-making, which may produce competitive advantages in which 'technology and data' multiplies the force of humans.

7. Making sense with technology and data

Taking the qualification of data towards a higher degree of organizational, economic and commercial sense-making, data management works as a vehicle of positive strategic change that sometimes may be associated with some extent of risk aversion. No matter what you're doing with a sports team, unless you are winning, there's going to be upset fans. Spearman touches this essential stakeholder consideration when arguing that "*At least you can then point to some objective reality and say: well this is our decision-making that's based on […] One of the big criticisms lot of times leveled against management or ownership is they're not willing to invest in the club. If you have this transparency, you know, we're investing this much, we're making the decisions in this sort of way, it's going to be a lot easier for the ownership to convince the fans that we're not just trying to suck money out of the club."* Hence, quantification of performance metrics in football is fueled with managerial power when being qualified in the sense that it constructs a pragmatic tool to manage stakeholder relations and to co-create a fruitful relationship between sporting and business activities of the club and its internal and external environment.

Finding a point in time where technology and data become even more decisive in football is a derived effect of how governing bodies and other rights holders play along. For instance, an extract from *FIFA's Laws for Players' Equipment* [47] stresses that *"a player may use equipment other than the basic equipment provided that its sole purpose is to protect him physically and it poses no danger to him or any other player"*. With this in mind, it makes sense that governing bodies allow players to take advantage of properly designed tracking systems in a game to prevent themselves from getting injured.

Football's global governing body FIFA allowed the use of technology and data during the FIFA 2018 World Cup in Russia so that coaches were permitted to receive real-time technology and data support from data analysts throughout the duration of games. However, it should be noted that the teams choosing to use this opportunity had exactly the same capacity to provide visual and statistical data[9] to inform in-game decision-making [48]. Therefore, the point

[9]During the 2018 FIFA World Cup, the movement of players could be tracked by two optical cameras. Analysts could send interpreted video clips about the team's performance to coaches on the bench via a tablet device [48].

of differentiation comes down to how intelligently and competently teams can apply the technology and data to make decisions. As the CNN article points out, the Dutch football legend Johan Cruyff once stated that football is a sport that you play with your brain. However, the current development proves that top football is highly associated with technology and data as supporting performance tools. Although sports tracking data may be optimally applied before and after a game given the complication of the 'stressed time slot' for coaches to manage their team comprehensively through data during a game, it is definitely means to an end in terms of fully preparing a team for an upcoming game or for constructive feedback after a game to influence future game preparations. There are always critical moments during a football game. For instance, it is interesting to assess what happens right after a goal scored, what happens right after halftime or what happens in the end of the game. Some players may be tired in the end of the game while others are not. In that sense, sports tracking plays a role in injury prevention but also regarding substitutions where some fresh players with competent offensive skills may enter the pitch with a positive determining impact on the outcome of the game. For example, Craig Duncan, a prominent sports scientist, argued already before the 2012 UEFA European Championship (EURO) that sports tracking systems (i.e., GPS in the case) worn during a match can help to prevent soft-tissue injuries [49]. The focus on technology and data to prevent injuries is backed by leading football physiologist Raymond Verheijen, who worked with Russia's team during the 2012 EURO. He said that up to 80% of injuries are preventable. Verheijen blames fatigue from overtraining in that matter, which is supported by evidence from a study analyzing 27,000 football matches demonstrating that teams playing after 2 days of recovery and facing opponents with a minimum gap of 3 days were 39% less expected to win at home and 42% less expected to win away [50].

Consequently, it is vital that players who do not play that much are kept fresh during the duration of a tournament whether it is the World Cup or for a club team; this is especially interesting in contemporary top football where the best domestic teams are expected to do well in domestic as well as international (e.g., UEFA) competitions. Therefore, the methodological constraints in applying technology and data are associated with the quality in which these factors are integrated in the daily operations of the club. For instance, FC Midtjylland bought and installed ChyronHego ZXY sports tracking system in their stadium as well at their training facility. The same technology for data use and data management for games and training session is methodologically important from a practical application standpoint because it makes it easier to compare the performance of players (it is also difficult to compare apples and oranges) while accumulating data for longitudinal studies [14].

8. Business promotes technology and data application in sports

The intersection between sport, technology and data is also a matter of segmented market places. Sport is dependent on fans. Without fan appeal, top football would not have the same economic scope. Global fan identification makes professional football a relevant commercial cocktail. The scope of the economics of football is very impactful from minimizing the level of player injuries, which may lead to better sporting performances and thus to an improved business model, to taking the data from the application of technology and turning that data

into fan relevant content. Spearman believes that the articulation of successful data narratives may lead to additional focus on technology and data management. He notes that *"One of the things you see in other sports that is really enhancing the application of technology is the success stories and I think the more public teams are with, you know, why they are succeeding using data, the more well known that becomes, the more of a market there is going to be for league wide deals for, you know, having that data so that you are not behind the curve."* Spearman implicitly tones the interaction towards teams not just gathering pools of 'big data' but rather putting data in play for strategic reasons and in a qualified manner.

The awareness about the potential of technology and data in football from a holistic perspective, which blends performance on and off the playing field, can affect demand. This is evident in what took place in professional baseball, i.e., when for example the Oakland A's and baseball became very successful using data, immediately the Red Sox became interested in the exact same ideas, so a team's success with 'big data' thrives in the competitive environments of top sports and business. Respondent 2c continues along this line in that *"The football world is a very wide term […] As a club, it is interesting to be able to measure all the actors, all the players in which one invests so that one can measure them against each other and say that one has a need for a specific playing type as left back […] Search the data and find what type of player one needs, his physical appearance, what kind of competencies he should possess, tactically as well as physically? So, I can see a lot of benefits in relation to this system (ed. ZXY) concerning giving them, who follow the sport additional experiences […] One can give them a range of data to 'nerd out' or, which one can continue to work with and then there is the last part, which is the commercial part, which one can couple with some corporations, which may enjoy this data in synergy with their own brand."* Concluding on this, professional football (sports) may face potent future opportunities in terms of tracking-driven and thus performance-generated commercialization.

In critically discussing and considering how to put technology and data to work in professional football in this context, the argument of 'qualifying' data becomes even more central as success in competitive settings is a matter of the quality of the process rather than the quality of the outcome. However, technology and data will most likely appear as prominent drivers in professional football in the future. The reasons for that may be contradictory; one stimulating reason may be 'the fear of missing out' in professional competitive settings as Spearman notes that *"Other teams were like: let's do it the good old way. But once they got left behind as dinosaurs, there is no way for them to continue with that mindset"* while another reason speaks to all the performance advantages associated with technology and data whether that's concerning sporting or business performance for football teams. Harrison and Bukstein [51], p. 3, argue that *"The core purpose of 'sport business analytics' is to convert raw data into meaningful, value-added, and actionable information that enables sport business professionals to make strategic business decisions"*, which is in sync with teams being triggered to apply technology and data because they know that otherwise they will fall behind. This development sparks new horizons concerning the perspectives on sport performance and sport business performance and thus allows for growth in the (digital) market opportunities in sports. Spearman adds that sport teams *"had to go out and invest in data, either acquiring the data or hiring people to analyze the data. Forming partnerships with data providers and with the media in order to kind of share that data as the fans became engaged with that.* From a business perspective, this requires investments by sports entities in one way or another, but the qualification process is a roadmap for strategizing future income potential

by building a bridge between 'big data' application on and off the playing field, e.g., through elements like fan engagement innovation, media content or clever sponsorship activation. Technology and data is a good proactive playing pattern to build better overall performances in football as there is a clear correlation between financial performance and sustainable competitive advantages [51]. However, many clubs have data but find it problematic to establish good articulation and narratives to enhance overall performance. Spearman notes that *"You really need that kind of success stories in soccer and I think there's been some examples like you know Ted Knutson at Brentford (ed.: Former Head of Player Analytics in the English Championship club and Founder of leading data and analytics platform StatsBomb), you know, had some success with data there, but I don't think any of them have been at this high profile kind of level where it's like this was a club that was bad and then they went and invested in data and now they are not."*

9. Paving the way for more comprehensive sports experiences

Better performances on the playing field and thus higher sporting quality most likely leads to better sporting experiences. Similarly, decisions based on data hold promising potential to establish good synergistic effects between the sporting and business experience. From data on local traffic patterns affecting fan transportation to games measured against scheduled game times and ticket sales and various other revenue generation categories within that context, e.g., merchandise, food and beverage sales etc. [51], to data on successful sponsorship activation slots during games, there are significant commercial advantages in data management. Building on the 'qualification' analogy, sports entities should aim to understand the practice and science of data analytics to sustain competitiveness. In striving for good business opportunities in this context, Spearman points that *"For business purposes, one of the key things is that fans in pretty much any sport, you know, really love their sport and they want to know as much about their favorite athletes or their favorite teams as they possibly can."* Data is a well-suited application for marketability purposes in the football industry, e.g., fan engagement, promotional efforts, and mediated content. Spearman finds an opportunity in the fact *"that so many people play Fifa, play Football Manager is just evidence of the fact that you want to engage with the athletes, not just by watching them on the television, and you know, drinking a beer at the pub with your mates, but also like know everything you possibly can about them."* This thought is in alignment with the focus group data, i.e., respondent 1a saying that *"There are bigger and bigger requirements from fans to get closer and obtain more knowledge"*, respondent 1e pointing out that *"The other super trend is the live element and that you can take something, which happens now, and touch it and create commercial constituent parts"*, respondent 1c building on the momentum of the discussion by adding *"That is heightened user involvement to an extremely high degree and it creates renewed interest leading up to the games but also during the games. There are more, who have the desire to come and watch the games because they become more engaged"*, while respondent 1d brings an interesting thought in terms of *"The fact that one can make own choices, you know, we give the user the opportunity to make some additional choices in relation to what they want to watch. That goes for a coach, who wants to know more about the physical aspects, it goes for a fan, who wants to know more about running patterns precisely regarding the weekly favorite player etc. That is a huge plus."* Professional football (and sports) falls under the umbrella of the 'experience economy [52–56] for what reason a principal purpose is to design and orchestrate comprehensive experiences for all relevant stakeholders.

Scholars [57] have concluded that sport organizations are not immune to profit motives and good stakeholder relationships and that trying to manage that involves the process of staging good experiences that are subjective in nature and a reflection of the interplay between consumers and the environment. A managerial objective is to boost the interactions from this interplay. Respondent 1c highlights that tendency in expressing that *"The competitive element in football has been considerably enhanced because there is fight for sponsorship money, prize money, rank in the league and all of it, and therefore one must optimize all the circumstances that mean that one can better win football games and maybe also attract more fans in the stadium by offering some other services. So, it is like respondent 1a says, 'big data', and it is statistics and numbers. We want to know more about all things."* Funk's [58] notion that sport consumers' situational experiences, e.g., experiencing a football match or fan-related content from a football club, are associated with a network of interdependent nodes of information about a specific sports brand, are in alignment with this managerial objective [59]. For instance, a football experience may be associated with nodes such as the legacy of the team, the quality of a star player, the cost of the ticket, the perception of club management, the value of entertainment, the decisions and the personality of the coach, team and player performances, social bonds related to the club, the size and comfort of the venue, the esteem linked to club results, and the escapism of being part of a tribal football community. These interrelated nodes of information inspire to emphasize an interesting discussion from the focus groups concerning the appeal of the football product on and off the playing field for stakeholders, which corresponds well with Cortsen's [13] point that research cannot be isolated from time and context. Respondent 1e voices that *"In this context, I am quite commercially thinking within my area […] When and during what time span can one use the data? There is, you see, the data, which the coach should have, which the fans shouldn't have. And then, there is the data, which the fans should have, so one can look back at the year before, which you also touched on with Kasper Kusk (ed. Danish professional footballer with national team experience), and then one could start to build more on individual players and then bring it into the following year."* Respondent 1b supports this articulated importance of time and context by using a relevant football analogy in stressing that *"Yes, very interesting. […] In football, whether one is on or off the pitch, is about the sense of time and space."* Respondent 1d goes on by categorizing football lovers, e.g., fans, sponsors, players etc., as content producers and viral platforms in that *"One is almost the journalist oneself in that context and then one looks at it and then it may happen that one uploads one's knowledge on social media and then something happens."* Respondent 2e continues in this direction and thereby seems to recognize that the strength of branded experiences are partly elevated by the football consumers, e.g., fans, sponsors or the media, by indicating that *"It is important to extend the game for the fans so instead of 90 minutes it can have a longer duration through the following discussions, which subsequently may be consolidated by new facets […] It's very important that the data, which it (ed. the game) produces, is accessible on some platforms, on which it is easy to share and cooperate and hand out things and say they support my discussion with you […] Such elements are super funny to work with and there is also a commercial potential in them."* That way, technology and data become elements with more influential power, i.e., in terms of sporting performances but also in business developing interactions with stakeholders via traditional media platforms, sponsorship forums and in shaping commercial fan engagement solutions. Thereby, they create value in extending and intensifying the hype and life around core events such as games and tournaments and central assets like players and coaches.

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10. Comprehensive football experiences equal better fan engagement

Technology and data have a great potential in professional football as there is a good level of fan identification with football brands whether these are linked to governing bodies, e.g., the brand of UEFA (in association with the Champions League as the world's most prominent club football league), leagues, e.g., the English Premier League, clubs, e.g. Real Madrid, or players, e.g. Lionel Messi [13]. The 'Psychological Continuum Model' [60] helps to elaborate on consumption patterns in sports. Its hierarchical structure of four phases: awareness, attraction, attachment and allegiance, provides a framework for how technology and data may serve to take the popularity of football to new heights, e.g., more in-depth insights related to one's favorite team or player, or to new target groups, e.g., technology and data savvy Millennials. For instance, technology and data from a sports tracking solution, e.g., ZXY, leveraged through a technology platform, e.g., an app, may improve a fan's knowledge of players from a favorite club, which creates a positive reproduction and reinforcement of the club's fan culture and fan identification level ending with 'lifetime fans'. This theoretical framework plays well along with focus group data and vice versa as the theoretical grounding assists in providing better understanding of how to create advancement from the lowest to the highest hierarchical level. However, the different phases of the 'The Psychological Continuum Model' should be subject to further qualification and thus not solely be perceived as an isolated hierarchical level, e.g.., being a Chelsea fan (attachment phase) or living for Chelsea (allegiance phase) may hold variations. Interactions are vital in this approach to add meaning to technology and data application to boost comprehensive sport experiences. The opportunities to generate new narratives and in-depth engagement, of which governing bodies including leagues and associations, clubs, media, sponsors and fans may take advantage, are interrelated with an open-source mindset and conscious and unconscious co-creation and co-branding[10] between these stakeholders. However, the focus group data reveals an interesting paradox in the fact that some stakeholders in this context are very innovative while others almost need to be pushed. Respondent 1a notes that *"Game statistics before the game and then raise it after the game on television; before the game one had placed this as a key match-up. How did it go?"* while respondent 1d articulates how such strategies may expand the value of the content in saying that *"I talk about it in relation to giving it a considerable story around the individual player historically as well as live."* The interactions or the interdependency between technology, data, sporting performances and business aspects linked to the sports experience like the product perception, articulation of the game, brand associations etc. are at the heart of professional sport as mediated and thus highly discussed entertainment. Respondent 2c adds that *"There is also an opportunity in extension in relation to the following storytelling (ed. after the game) that one can put in a context. Afterwards, it may be interesting to watch where Morten Bisgaard (ed. former Danish National Team player and current football expert for the media) went in and did a thorough analysis of his (ed. William Kvist, who is a current Danish National Team player) game from minute to*

[10]Co-branding in this context means that the purpose of branding, among other things, is to create value (also from an economic standpoint) and that co-branding becomes a manifestation of this purpose by including a 'win-win scenario' aimed to construct synergistic effects based on the branding activities [61, 62].

minute and demonstrated that his performance not at all was connected with what he was accused of in the media. So, one can say that there are also some really good opportunities for all actors, that they get to tell the story that they want to get out or to put it in a context in relation to other players." Another dimension of this is articulated by respondent 2e in that *"There are many stories […] What one can add to a player, which maybe, there is a 'gray*[11]*' mass of players, which are totally anonymous for the fans. They will suddenly be interesting because there are more stories that we can attach to the data in 12*[12] *different ways."*

What holds meaning concerning technology and data application to enhance sport experiences is the improved quality of the user or fan experience. Respondent 2a views it as a valuable add-on in that *"All this with in-game index*[13]*, is what they call it. It would be a nice part with push notifications […] One would drown oneself, if one had to find this statistic"*, while respondent 2d participates in mentioning that *"We can also see fans that what they do during games, that they would like pushed information. Then, one would like that someone pushes something while one is sitting and watching the game. After the game, if one has seen the game, one would like pulling information […] Then, one can adapt the different tracks depending on one's situation as a fan."* In alignment with the premise that meaning and understanding are derived from language and thoughts [26, 27], the term 'big data' in sports is a symbiosis of opportunities and flexibility, which respondent 2d admits in that *"In relation to the commercial perspective, then one can say that we are dealing with data, which in one way is flexible, i.e., they can be attached to many different things in cyberspace as well as in many channels. One can insert statistics in all kinds of advertising, one can place them in different contexts. One can do a lot with data as soon as they are detached from their original medium and can thus be attached to some completely new nodes of data in some completely new contexts. And it makes it possible to, one can say, to follow the game well beyond the 90 minutes but also to break into new contexts in relation to other types of events as well as other types of media channels, e.g., as Carlsberg did with a channel that runs on a television screen with some stats after the game and so on."* Spearman supplements "*A lot of the data we have can be used to gain a competitive advantage from a competition perspective can also be something that increases engagement among the fans. […] It increases the number of ways, in which the club can interact with the fans, increases the number of products that the fans might be willing to pay for either from the clubs or from the media in order to kind of learn more about their favorite athlete and delve deeper and really understand who's good and why."*

11. Knowledge-sharing between sports and business

Taking the data and connecting it to the game's multi-dimensional aspects brings an interesting level of content about clubs, players and commercial stakeholders, e.g., Real Madrid has a

[11]The terms 'gray' in this context holds the meaning of the players not standing out in a significant negative or positive way.

[12]The number 12 is just a number used to emphasize that data provide many opportunities (and that these opportunities are not limited to 12).

[13]An in-game index allows data analysts to break down team video and index clips for team and player performance analysis and thus to visually present highs and lows during a game coupled with in-depth statistics.

70% possession rate and Toni Kroos has 95% successful passes and that plays along with the sponsor activation of Emirates with an average of +95% on-time arrivals. Such narrated content can assist in brand management disciplines by building, developing, and sustaining a strong level of brand equity as a 'hybrid notion' of sports branding [13] and cater a better understanding of the football entities' decisions and actions. According to Spearman, Opta Sports, a sports data provider, does *"a really good job with kind of simple statistics."* In a Tweet [63] from the 29th of June 2018, the Opta Twitter account 'OptaJoe' Tweeted:

A very simple Tweet like that generates a fair rate of engagement in terms of comments, likes and shares so consider the potential in more sophisticated content. Spearman adds that *"The visualization element with the tracking data is going to be very powerful […] Now, we see it a little bit where they'll be like oh did you know this guy has run 14 kilometers in this match […] Visualizing pitch control, visualizing open space, visualizing dangerous zones on the pitch using tracking data-based models is going to be the next step there."* Therefore, the qualification of data is also a derived effect of the sophistication, i.e., the use of 'big data' is more interesting when it exceeds just running statistics while taking more sophisticated sporting data and going beyond its mere sporting performance focus to seek ways to let football actors on one side, e.g., managers, coaches, and players, interact with fans, sponsors and the media.

The scope of technology and data in professional football grows when it is inserted in a context of co-creation and knowledge-sharing. SAP was mentioned as an example of adding new dimensions; e.g., the measurement of players' cognitive skills. How about the creative opportunity of measuring emotions? Such aspects are already in play in the commercial arena of sports, e.g. sponsorship effectiveness enhanced by sentiment analysis or integrated algorithms. Respondent 2f touches this in that *"In reality, this is about how one can obtain an experience, a feeling of these people while they play […] For instance, one can measure from other sensory data just like: now, he is about to blow up*[14] *or this guy is good at getting some emotional into it […] Can one beforehand by the help of 0.02 seconds latency find out where the next emotional outburst takes place […] It is over here that we need focus on our camera because it is right here it happens […] Next time the two will meet, when they get within 5 meters, then they know that they are going to kill*[15] *each other. Can we spot those situations?"* There is an interesting knowledge gap to fill in terms of applying technology and data to co-create better sport experiences, which may be facilitated when working strategically with gamification [14]. Gamification may be defined as the *"use of game design elements in non-game contexts"* [64]. However, the gamification concepts challenge the traditional charm of football (and sports), which is protected by fans romanticizing how it was in the old days when the game was merely about 22 players chasing a ball within the lines of play controlled by a referee and without the influx of technologies like Video Assistant Referees (VAR as implemented in the 2018 World Cup in Russia) or sports tracking systems. Nevertheless, it is part of our society and now 'part of the game' for what reason football entities should praise all the opportunities that come along with technology and data but with a strategic 'gamification' approach of thoroughly considering when technology and data act as a winning strategy. For instance, it seems like the application of the VAR-system needs modifications to accommodate teams' perception of fairness in the World Cup, e.g., why are some situations subject for reviews and others are not? Respondent 2b comments on this debate in that *"Of course, it triggers me based on our assessment of players. That is what we spend much time on. We have to assess if players are good or bad on a scale and we cannot just assess a player, who has scored a goal and say that he is better than another player. Therefore, it triggers me at the thought of making 'how good the players really are' more efficient. I also looked at the video up here and then they needed to obtain points for many parameters."* Respondent 2f states that *"Can one use these data to already during the game to get the story about the people that play. And it has to be live. It has to be like that when two just destroyed*[16] *each other a couple of times, then the next time they get close within 5 meters of each other, then we have to be 100% sure that we have a spot on your faces because now he needs to get it […] The story about the people, who really play this game and the life that unfolds in this game. It is just as in other sports very mental to play football. And who is in the zone and who is not in the zone? Can one see that? It is interesting to see people who perform well because they emotionally are alright and are in the zone."*

[14]Blow up in this context is an expression of being very emotionally influenced, e.g. a player may work harder or be irrational and commit a stupid foul.

[15]Kill in this context acts as a figure of speech for being on top of or winning the battles that takes place on the pitch in a professional football match.

[16]It is a metaphor along the same line of meaning as the 'kill' metaphor.

12. Knowledge and co-creation frame the football experience

The discussion becomes a matter of the charm, knowledge level, sporting and business value, which are vital elements attached to the game. In bridging existing knowledge gaps regarding technology and data in football, it is evident [14, 51] that there is an edutainment [52] element capable of blending education and entertainment at the benefit of enjoyment for the game's stakeholders. When watching the 2018 World Cup, it was interesting to witness how the media articulated France's 4–3 win against Argentina in the round of 16 as a celebration of fantastic offensive football. There is no doubt that the game presented excellent finishing skills and fine offensive playing patterns, but one should note that sparkling offensive skills sometimes are derived from questionable defending. If beating Argentina 4–3 in a game with 7 goals, and some great goals esthetically, serves as a quality performance indicator, there is a need for a higher sophistication level. The game was very entertaining for football lovers. However, it is interesting to look at the contrasting perceptions among the media and football fans in a tiny (definitely when measured on population size) football country like Denmark after their team's 0–0 draw against France, which qualified Denmark for the round of 16. Expressions like boring and destroying defensive football characterized part of the country. Of course, football's passionate texture covers both extremes, e.g., the very positive and praising manifestations of Denmark's success of making it through the group stage but also the very negative and complaining manifestations. That's football and that's what the passion of sports is capable of. This is something that the football world should embrace as an opportunity. The point here is that the real interesting question(s) in bridging existing knowledge gaps may exist in the form of asking 'what is at stake here?'. This question includes time and context when asking 'who are influenced by what is at stake here?' and 'what is the meaning of time in that regard?', e.g., there are relevant moments before, during and after Denmark's game against Croatia in the round of 16. If one is a football fan but also a professional coach, the dominant contextual factors when asking the question of 'what are the conditions for the game?' will entail greater nuances or sophistication. For instance, such a person may have liked more entertaining offensive football from Denmark against France but would also acknowledge the meaning of time and space in football. Thereby, this person would know that France would most likely take advantage of the opportunities if Denmark's defense was positioned by the midfield line in most of the game instead of being positioned more defensively. So, a good understanding of the game may be positively enhanced by technology and data, e.g., sports tracking data, as an engagement tool in the discussion regarding the World Cup and thus illustrating that a game and the outcome of a game may somewhat be controlled without necessarily having the ball but by controlling the space in which the opponent wants to operate or by 'tactically tricking' the opponent to operate in certain spaces in which it is tactically beneficial to conquer the ball. The successful coach José Mourinho won a couple of titles with 'underdog teams' in this manner.

Strategic application of technology and data may take different forms, e.g., defensive vs. offensive approaches to winning games on the pitch, data-driven decision-making in the business side to support strategic execution or strategic gamification elements to provide edutainment. Spearman understands that football is a dynamic phenomenon, the importance of momentum on and off the pitch and acknowledged a few vibrant development patterns surrounding the game in adding that *"One is the fact that fans are becoming more educated as time goes on […] There are things that are measured now that may not have been measured before and fans become aware of that*

[…] Trying to think of a good example of soccer […] In baseball, we were not used to measure on-base percentage. We were not used to measure these advanced statistics […] When you mention them, people would just go out and zone out because it's not part of their comprehension. The same with the expected goals, like you know, three years ago if you said expected goals to anybody outside of somebody who's, you know, in soccer analytics, they're just going to be I don't know what that is. Now, it's on sky sports and so the fans are becoming more educated about these different concepts, which allow them to appreciate it and enjoy it when they see it. That being said, I think there's also, you know, the fans are never going to be. You don't want the fans to be like 'mathematically' in their appreciation of the game, it needs to be intelligible. Respondent 1b supplements this notion in that *"Very simplified, it is self-evident of course, but can the commercial partners and suppliers, you know, associations, clubs and what there may be, if they can figure out to collaborate about it and develop content, which X (ed. respondent 1d) touches on, well then it will be well received by the target group in the end and then you will to a far higher extent create a pull-effect."* Both Spearman and the focus groups agree that competent and user-friendly co-creation between various relevant stakeholder groups in football may elevate this opportunity. Spearman notes that fans *"are not going to be mathematically inclined necessarily, so you don't want to be showing equations or models. Things need to be understandable just from first glance […] The visualization component is extremely important and good visualization has always been an important part of communicating with the coaches and the athletes themselves. […] It's even more so with the fans, I think, because it's not their job to understand complicated models. They just want to appreciate the game."* The strategic embracement here by football clubs lies in that there is now a good (or at least better than 5 or 10 years ago) awareness level of the existence and importance of technology and data in football but football's stakeholders should work together to accommodate the expectations about applying it. The digitization of sports is a good option for football's central actors, e.g., governing bodies, clubs, coaches, players etc., and their commercial stakeholders but the possibilities of technology and data application should be comprehensive and founded in competent people with thorough understanding of the relevant contextual factors making it sophisticated in the back-end but simple and user-friendly in the front-end.

13. Bringing data, knowledge and strategy to life: recontextualizing football economy

The ZXY system is capable of commercially intensifying the knowledge gained from sports technology and data and thereby to help football teams realize their strategies in this sense. Inductively, the research data provides sufficient grounding for proposing a conceptual framework, cf. **Figure 3** below, which portrays how technology and data recontextualizes traditional sports (and football) economic models [65–69]. This case of investigating data from sports tracking technology in football shows the point of professional football clubs investing in sports tracking technology and data primarily to improve the conditions for sporting performance. The sporting performance of a football club is based on prevalent dimensions such as physical, technical, tactical and mental dimensions but in this context, it is imperative to underscore that the complexity of football is also linked to football being a team sport. Therefore, the social and hence culturally influencing dimension regarding the cohesion of and the relationships within a team matters in football performances [70]. In this context, so does the sport specific technological dimension. For instance, in cycling or motorsports, it is common to work with minimizing wind

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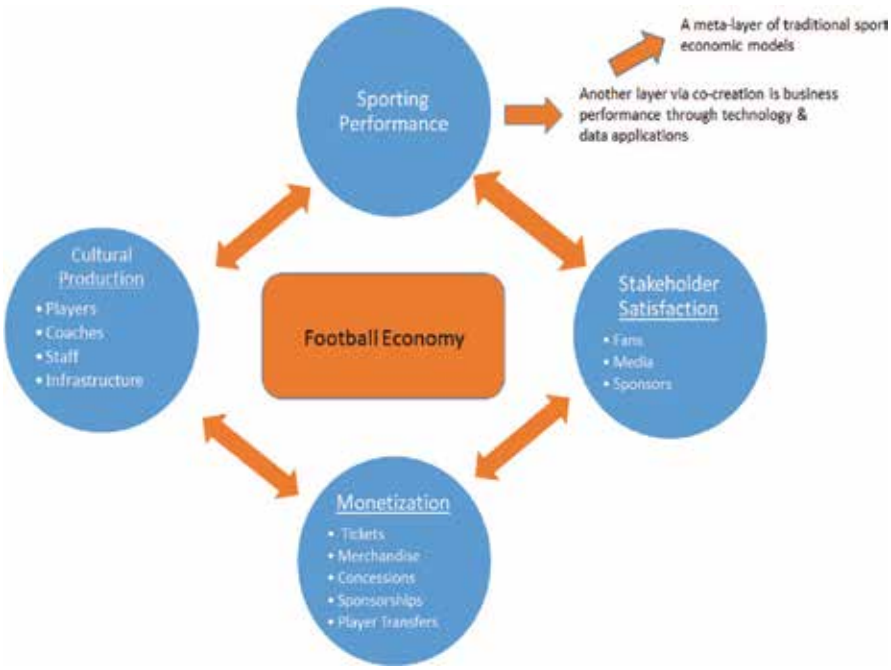

Figure 3. Conceptual framework - recontextualizing the football economy via technology and data.

resistance to influence performance. In sailing, it is common to look at the construction of the boat. In football, technology (and thereby data) also plays a vital role in influencing performance. However, the difficult part is to work on the social and cultural dimension. The relationship between data, knowledge and actions is vital for football entities. Football entities are working with 'big data', i.e., large data sets, which produce lots of knowledge. However, knowledge is not enough in itself. Everything must be qualified and inserted into a set of actions, which in the end determine the outcome of a game. Consider Germany's football team, which came to the World Cup in Russia as reigning champions. The German team works intensively with data, has qualified and effectual knowledge within this field but the team seemed 'saturated' (many players had already won the tournament in 2014 and also played many games throughout the year for the respective top club teams that they represent) and not engaged enough in the actions on the pitch, which may help to partly explain the team's early exit of the tournament.

Clubs succeeding in enhancing the quality of sporting performances will face improved stakeholder engagement and satisfaction, e.g., higher attendance levels, better media articulation, and increased sponsorship interest. All these elements may serve as positive influence on sporting performances, e.g., happy fans may positively influence the confidence level of players, while also influencing monetization opportunities. For instance, clubs can capitalize on more fans coming to the home games in terms of increased ticket, merchandise, and sponsorship sales. In addition, players that perform above average may be subject to positive articulation and may translate 'being talk of the league' into lucrative transfer sums. These capitalization dynamics of a football club lead to cultural production, i.e., a process that may also include negative and positive reproduction of culture [71], in which the club will invest in shaping the culture of

the club, e.g., investing in the roster, the team functions or the club infrastructure. Just like the monetization aspects can be traced back to the stakeholder satisfaction, e.g., better profit margins may spark the club to re-invest in fan engagement solutions, the cultural production also influences the monetization aspect in that a football club constantly evaluates the 'strength' of its culture, i.e., if there are irrational investments in the cultural production (buying the wrong players), this fact will affect monetization negatively. The cultural production implicates that investing in the right coaches, the right players and thus building a strong level of cohesion in and around the team with the right relationships on the pitch (in and between the various lines on the pitch) will influence sporting performance positively. Of course, this conceptual framework is a construction, which to some extent takes a 'ceteris paribus' perspective, because the practice of running a football club is highly dependent on different parameters. One vital parameter is competition, e.g., there is intensive competition for the best football players, which increases the costs of investment in fully developed quality players (another reason for investing in technology and data to optimize performance enhancing details from this investment such as optimization of talent development or of purchasing fully developed players). Another important parameter is the market size and constraints, e.g., is it a club like FC Bayern Munich, which is operating globally, or is it a club like Werder Bremen with a smaller market size? Additional parameters like the club's facilities or stadium, its commercial competencies, the strength of its league, the appeal of the league's competition format, the level of competitive balance in the league, the strength of the league's media deals may be decisive factors influencing the various parts of the framework. However, the interesting recontextualization aspect of the conceptual framework is associated with technology and data, which constructs a meta-layer that emphasizes the importance of co-creation and co-branding due to the application of technology and data in this performance-related management of the sport and business nexus in football clubs. As mentioned earlier, the qualification of technology and data use (including competence development of the organization) and the derived co-creation and thus the co-branded and 'hybrid' branding activities build a fruitful bridge from improved sporting performance to optimized business performance in the club. Thus, the business performance is also depicting an interdependence with the different parts of the conceptual framework, i.e., stakeholder satisfaction, monetization, and cultural production. This is a somewhat artificial construction grounded in the empirical data and in relevant theory but it depicts the demand of the football industry in terms of the constant hunt for performance improvements in a very competitive and dynamic environment, which is highly influenced by technology and data.

This development gets a more lively and vibrant strategic meaning for clubs, players, fans and other sporting and commercial parts of football's eco-system [14]. All these parts should be interrelated in ways, in which technology and data may bridge the gap to more thoroughly understanding football performance, at the cognitive level and concerning tactical, physical, technical and (perhaps) social[17] and technological aspects. One development that Spearman saw influence this context was the framing of pitches in baseball, i.e., *"A good example comes from baseball with the pitch framing […] One team kind of recognized that the way, in which a catcher catches the ball can influence the umpire in deciding whether it's a strike or a ball. So, something that's*

[17]Football is a team sport so the social capital may be relevant to discuss in relation to how technology and data are integrated to influence sporting and business performance. Putnam articulates the significance of social capital *"To build bridging social capital requires that we transcend our social and political and professional identities to connect with people unlike ourselves. This is why team sports provide good venues for social-capital production."* ([72], p. 411).

in the strike zone or without. And this was not something that was being measured by too many people. They realized that this could actually result in, you know, maybe like three to ten wins above […] By finding somebody who's good at this pitch framing. And because nobody was really measuring the statistic, it wasn't something that cost a lot of. So, they were able to go find somebody, who was really, nobody thought was a terribly good player […] Pay the team to trade for him and then go and become very successful with this player." However, this vitalized notion of technology and data goes beyond coaches and players and into the sporting and commercial strategies, i.e., looking at the long-term sustainability of the club, in football and sports. There are clear business benefits of increased data and economic advantages of more decision-making on 'qualified' data. Respondent 2b emphasizes this in that *"If one had this equipment oneself, then I could imagine that one could set it up at a sports field or something like that and then one could try to reproduce a free kick goal, Ronaldo's running pattern, how high he jumps and then one could get some rating that now, you are 50% Ronaldo and then one could compare oneself with friends, who may be 60% Ronaldo."* This is value creation in real demand created around the game of football and its application of technology and data that may inspire football fans of various ages and across international borders to 'Play Like A Pro' [14]. Such concepts are well aligned with current trends and tendencies in the football landscape, e.g., promoting the crossroad between football fitness, physical activity, and public health benefits [73, 74]. Hence, it may also unfold in relation to strategic sponsorship activation[18] like seen in the 2010 World Cup in the form of Castrol's 'performance index' showcasing the skills of Cristiano Ronaldo and other top players and to set the agenda for what these top players are capable of regarding football performances [14].

To strategize this context, there is an obligation for stakeholders in football to intelligently co-create and co-brand. One challenge is that the strategic organ in football organizations is all too often too distanced from the operational and daily contexts to understand how to construct or shape the knowledge and skills, which can guide competent 'qualification' processes of data and data-driven decision-making in the organization (if decisions really are made on that foundation?). For instance, there is interesting potential in trying to 'qualify' technology and data in a context of 'hybrid' sports branding [13], e.g., taking the economic benefits of finding the 'right players' with the 'right competencies' but understanding how to leverage the branding interplay. The latter refers to the hybrid element(s), which may beneficially be orchestrated across various platforms when there is a 'qualified' construction of the specific player brand in the context of the sport (football), the league, the club, and its commercial stakeholders. This working approach will construct 'new meaning' in terms of talent identification, recruitment, and development from a 'sport of sports' and from a 'sports business' perspective.

Technology and data can help to demonstrate somewhat hidden qualities of players and assist clubs in winning and players in developing and it can be used by the clubs for various sporting and business purposes, e.g., creating positive transformation[19] on the transfer market and expanding the club's economic transfer balance and entire valuation from these transactions [38]. Spearman indicates that *"For example, with expected goals, which is one of the more prevalent statistics in soccer, if you're able to identify a player […] So, with beyond the expected goals where you're looking at a player, who is able to put himself, create space in dangerous situations, but maybe*

[18]Strategic in the sense that it is aligned with Castrol's strategic foundation and brand.
[19]This element of transformation is integrated in the 'cultural product' of **Figure 3**, cf. below.

the team doesn't, is either incapable of getting him the ball while he's there or doesn't recognize him as a player to feed the ball to. But because he's creating this space in dangerous scenarios he's creating an advantage for his team, that his team may not be recognizing. So, if another team were to go identify this player, you know, transfer him in, and then potentially could be very successful if properly fed the ball so that it's something where you might find an undervalued player in that way in soccer."

14. Segmented marketplaces and learning to spark football's innovation

Football is a segmented marketplace. Budzinski and Satzer [75] argue that the business of sports is characterized as multisided markets, in which there is a strong interdependence between different business markets[20], e.g., sponsorship income may be affected by ticket sales and vice versa. Spearman notes the interesting aspect in this in that "*One thing that a lot of clubs may not be thinking about is how to leverage nationalities in order to kind of bring in more revenue for the team. So, when you're thinking about a transfer, you're thinking about how these players can impact a locker room, how this player is going to impact the team. Sometimes, you might not be thinking about how this player is going to impact the viewership."* There are market specific examples according to Spearman, e.g., *"A player like Christian Pulisic. Nearly every American heard of him, who knows anything about soccer player. The Dortmund player. He's a player that you know. He might not be the best player at his position, maybe not even in the top 20, but if you bring him into a big market team like Manchester United or Real Madrid you're probably going to see a revenue spike from the United States segment of the population, just because that's a huge market. And people love this player and they're very likely to take an interest in your team and support it in a financial way. If you have a player like that, I don't know if that's something that a lot of front offices are thinking about necessarily. Sort of, you know, the kind of players that would engage the fans rather than just…"* This citation speaks well with strategies like that of Manchester United, which aimed to strategically capitalize on players with good grounding in various market places, e.g., Park Ji-Sung from South Korea or Javier Hernández from Mexico. It is evident in the data that there is an interesting dynamic between how data influences team and player performance dynamics while influencing business dynamics, e.g., the multisided market analogy, and football economic factors as well. For instance, it sparks strategic questions as to how this may open up for new segments or how data can help to project who may become a superstar on the pitch and assist in starting the process of capitalizing on that off the pitch, e.g., Christian Pulisic may be a good bargain for current American brands? Football as a segmented market place works with the notion that without engaged audiences, it is not as interesting from a commercial angle and data can create new blended commercial cocktails with clubs and their actors, e.g., players and coaches, and fans, sponsors and the media. However, bringing things to life in the right (qualified) version is significant (keep Mead

[20] "The name 'two-sided' market was originally chosen to characterize the two sides of demand (customer groups) a supplier on such a market must deal with. However, since every market consists of 'two sides' in a different sense (supply and demand), the adequateness of this name is subject to controversy, e.g., [76]. Next to the simple enhancement towards cases of more than two distinct customer groups ('multisided' markets), the term 'platform' markets is preferred by some. Yet, 'two-sided' or 'multisided' respectively seem to be the established terms, wherefore we will use them in the following" ([75], p. 69).

and Blumer's notion of meaning, language and thought in mind). Spearman sees that connection too in stating that *"You're teaching a language too, I guess, like with the schematics on the tactics board. You know like, if you see tactics board the first time you have no idea what these X's and O's mean but then you learn the language and so I think. Coming up with a good language visually and then teaching it to the fans and to the athletes and to the coaches."* So, strategically, this is an acknowledgment of the fact that football is about 'learning'. The powerful analogy of a teacher being the smartest mathematician but not knowing how to convey and articulate his/her professional knowledge to facilitate learning for his/her students does not meet any ROI, ROO or ROE indicators. It is the same in football. For instance, data analysts must be able to arrange and communicate their professional knowledge to coaches and players and just like the business side of a football club must do the same towards stakeholders like fans, sponsors and the media.

Football clubs are starting to work even more strategically on influencing customer-driven innovation. Spearman notes that *"You've seen a little bit of this with hackathons […] FC Nordsjælland recently had a hackathon where they gave people access to tracking data. Some fans and analysts and let them see what they could create. Manchester City did the same thing a few years ago. Bayern Münich has done it before. It's a way, it's not going to engage with the community at large necessarily but it's kind of a first step I think in that process because you're basically saying here's some data let's get the people who are real nerds about this and give them a chance to interact with it. I think you can go well beyond that because you kind of see, you know, once you build more tools in terms of how to interact with the data, it lowers the bar for how technical you have to be in order to kind of develop new ideas with that data. So, when you have like ways to visualize it when you have a kind of, you know even video games, where you can kind of try out new things with the data, with historical data and see like if we had done a different tactic of these 2016/2017 season. So, I mean, I don't know if this is how it's going to go but it would be interesting if in the future, you know, like say. Say Manchester United released kind of like a simulation sort of Football Manager style that let fans try different tactics during that season to see if they were able to come up with better results and then you know crowd-source that sort of thing."* It engages the stakeholders and connects 'big data', stakeholder communication and new innovation, e.g., in involving new segments from the eSport crowds that now have become part of some professional football clubs. It is also seen in the sporting performance side, e.g., the Dutch company 'Beyond Sports' uses virtual reality to enhance tactical development.

15. Better understanding of sports and increased marketability

Along with the 'qualification' discourse in this chapter, technology and data businesses also move into a more crowded market place so simple data does not provide much relevance in terms of marketability and providing more in-depth understanding of football for the coming generations of prosumers. Spearman supplements in *"That's why I hate things like possession stats, because it's just a single number […] It's not taking into account any of the domain football knowledge that you have […] So, building a model based on possession and saying like teams that have 70 percent possession win 70 percent of the time is pointless."* This is certainly seen in how less understanding of the game may lead to misinterpreted conclusions that the team with extensive ball possession on the opponent's side of the pitch deserves to win without taking into consideration that the defending team had a clear tactical plan based on own strengths and weaknesses and

focused on transition opportunities. Or you can have statistics showing that one team plays the ball forward a lot without taking into consideration that these passes primarily stem from the right back kicking pointless long balls without seeing intelligent opportunities based on second and third movements (ed. from other players than the player in focus for ball reception).

The market expects more from technology and data solutions in football today and that is a relevant interplay. Spearman adds that *"You're not taking into account any of that information in building the model because it's based on one number. So, any model you have, you have to be very clear about what's gone into it. So, that's why, like with my approach, I don't like using neural networks because I want to be able to explicitly say, this is what's being accounted for, and this is how it's being accounted for, and this is why, when it's wrong, it's wrong. So, I guess with, you know, creating opportunities you have to say like with an expected goal's model, if you just take into account the location of the shot you say; well, I think given the shots they took they should've scored three goals but I'm not taking into account the location of the defenders because I am not using tracking data for this model, which means that if they park the bus and there are 11 defenders behind every shot. Even if the shot came from 10 yards away, it doesn't matter. You know it's gonna be a terrible shot because there are 11 people there."* So, this proves the importance of qualifying the chosen methodology, it proves the importance of qualifying the data and it paints a picture of the vitality of clearly understanding opportunities and limitations of technology and data application in professional football. For instance, to go on with Spearman's example of the expected goal model. Other factors of interest may be 'who is taking the shot?', 'who is the keeper?, and 'who are the defenders?' The round of 16 game between Portugal and Uruguay showed Portugal having lots of possession in front of Uruguay's penalty box in the second half and even when Portugal came into that zone Uruguay defended quite well led by defensive star Diego Godin. In that sense, it also interesting that Fabio Cannavaro was the last defensive player to win Ballon d'Or, which dates back to 2006 as there is high focus in football cultures on the players, who score the goals. Spearman highlights the importance of clear communication when presenting the data, i.e., *"When you're saying things about your models, never say it with too much forcefulness, because you have to be explicit with the things you're not taking into account in addition to what you are taking into account."*

In that sense, Spearman also stresses the many opportunities in tracking data influencing the future of technology and data in football. *"Yeah, I think the tracking data is huge. So, I think the tracking data really is the way of the future […] Any team. Even any media provider that's not trying to kind of, represent the game using tracking data is going to be behind the curve […] There are a lot of reasons for that […] You are seeing a lot of new models come out that involves the tracking data. A lot of new approaches with space and so we're beginning to quantify things that coaches, and analysts and athletes have known for a long time about space creation […] One of the biggest kinds of disconnects between the fan experience and the people inside of clubs, is being able to see the game in a spatial way. Like our fans are going to watch the match and be like OK, well our guys took a lot of shots, they should have won, or our guys just looked better today. And that's kind of oftentimes influenced by the final score line you know."* Thus, the data presents marketability opportunities in bridging the knowledge gap between the sporting side and the stakeholder (fans, sponsors and the media) experience and in understanding the importance of time and context or written in football language: 'time and space' are crucial. Spearman touches on that, i.e., *"The current data we have that's presented on Sky Sports is not spatial. And so, for the fans to really start to kind of understand the way the coach might look at it, I mean, you'll get a lot of clichés afterwards, like you know, we got out there and we pressed really hard. There are no metrics around pressing hardly so there's no way for the fans to like really fully understand, what it means to look like other*

than just kind of watching him be like OK I saw a few times when the guy with the ball was dispossessed. There's really no way to kind of visualize that pressing and with tracking data you can start saying; OK well this is how fast they were. Once a player gets the ball on average they were closed down at this rate […] Even more dynamically, like this was the space available to a player when he got the ball. That area shrunk by this much. And then you could show kind of an average way, in which that occurs to visualize how that pressing happened." So, this chapter should motivate stakeholders in professional football to look at how they develop and apply technology and data. Blending these data with knowledge of the game is both interesting and complicated; just imagine when a player receives the ball on the last offensive third of the pitch. Does the defender(s) fall back or does one of them push up to press the player with the ball. Spearman underlines how conveying the data competently makes it less complicated and more marketable in stating that *"One of the big ways, and this is something that I've done a decent bit of research on, is kind of making it easy to see complicated domain knowledge […] Simplifying some of the domain knowledge, not necessarily removing information but making it easier to see. […] A good analyst, a good scout is going to be able to watch a match and see when there's space when there's like a region of space that's being controlled by a player. As a fan, I may have some sense of that, but it's going to be very difficult for me to have the same level of knowledge that the analyst or scout might have. However, that analyst or scout, the reason they have the knowledge they do is because they spend so much time watching this match, you know, putting this information through their own mental model. And theoretically, if there is a mental model there, which I would argue that there is, one could use data to build a data model and then visualize that in a more meaningful way. So, getting back to the notion of pitch control. The pitch control field is something that could be easily overlaid kind of in a, you know, a video feed setting, that would allow the fan, who maybe doesn't have those 30, 40 years of experience in the sport to see; ok well right now Messi has moved this direction, which has opened up this huge space for Neymar or Suarez to move into and to receive a through ball from the midfield or something."* Making it easier to comprehend relevant parts of the game offers opportunities for commercial stakeholders to interact so that all parties come closer to the common denominator of what's at stake in the game. But 'big data' also provide the heterogeneous market dimension that the data can go in many directions depending on the eye of the beholder for what reason qualification also becomes a matter of competent 'framing'. Football is a multidimensional game with much decisive randomness[21] for what reason technology and data can facilitate relevant debates and more importantly learning.

One of the main changes to the understanding of football, which technology and data provide, is that this context creates a relevant cohesion between the sporting and commercial focal points and how to strategize and capitalize on that. For instance, Spearman mentions that *"I will start with the stakeholders. So, one of the things a lot of times, you know especially with a game like soccer, which has a lot of elements of randomness. It can be very easy. And you see it a lot where you know a coach has a bad record […] Everybody wants to string the coach up, to get rid of him […] Having a common language that's maybe a little bit more objective and that's kind of what I was saying about the data. You can overcome biases. So, having that common objective approach can allow the fans and the owners to say; OK yeah, we've lost three of the last four games, but if we look at our expected goals we've been performing really well.* Data can help clubs strategize decision-making, communication, fan engagement, sponsorship work and it becomes a risk management tool as well to minimize damaging managerial

[21]Look at the outcome of the games in the World Cup, e.g., shots deflected ending in a game-winning goal, the influence of the VAR system, a linesman missing the offside, etc.

decisions. Spearman mentions this example, i.e., *There's no point in firing this manager, whom we have spent tens of millions of dollars to bring in. Just because of a few bad results that were unlucky. And you can now define unlucky rather than just saying we think it's unlucky. So, I think from an ownership stakeholder perspective, that's going to be really useful in avoiding these sorts of bad decisions that lead to, you know, okay you've had a 10-million-dollar contract for this manager. Now we have to still pay him that, but we have to pay this new manager another 10 million dollars. This is just a waste of money."*

16. Concluding remarks and future research

Technology and data improve the commercial outcomes for teams, not only by raising the sporting performance of the athletes (and thus winning more often), but also by allowing the data to be commercialized. This includes technological innovation, biostatistics, movement data, and other game-based information, which improve how a football club manages performance and enhances the circumstances for unfolding its talent on and off the pitch. This commercialization creates still more fandom above and beyond what's driven by the sporting outcomes and thereby opportunities for better comprehensive fan experiences and innovative commercial solutions that can support revenue generation. Currently, though, the sheer amount of data that is becoming available to sporting enterprises is difficult to harness and use effectively both for technical reasons, but also due to a lack of financial and human resources. Yet, the fear of missing out (FOMO) is causing some organizations to prematurely (that's not good strategic execution) engage the data anyway.

Commercial sub-optimization may be prevented with the use of technology and data. However, what needs to happen is that the data needs to be qualified so that knowledge-sharing, individual and organizational learning co-exist along with the aim to apply technology and data to improve sporting and business performances. If there is a lack of resources, e.g., in terms of financial and human capital, one way to overcome this constraint is to strategically invest in technology and data to optimize the utilization of these forms of capital. In such, technology and data are potent vehicles that can change performance in the sport and business nexus and by catering to new audiences and improving the engagement with existing audiences, there is a good chance of increasing profitability. In the tracking-driven and thus performance-generated commercialization in football, data accuracy is central so qualification should become a matter of: circumstances for data collection (e.g., methodological conditions), persons behind the data (who collected the data?), avoiding to fall in the trap of 'data for the sake of data' (quality of data should outshine 'quantity focus'), and of creating effective platforms for user involvement to bring the data to life in a wider football context.

Future research should include a better understanding of the intellectual property issues of who owns this data—the athletes, the teams, the governing bodies (e.g., FIFA, UEFA, national football associations, and leagues like the English Premier League), media companies, the public (is it public data like boxscores), the technology companies themselves? In some sense, whoever owns or co-owns the data will be able to profit off of it, yet based on the Coase Theorem, the data *will* become commercialized if there are economic reasons to do so[22].

[22]Coase [77] noted that, under various assumptions, regardless of who owns an asset, that asset will be used in a way to maximize its net value.

Additionally, research on the strategic tradeoff between generating profit off of the commercialization of the data and whether the release of the data becomes an advantage for rivals.

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Section 3

Innovative Sports-related Technology: An Example

Chapter 5

Sensing Technologies in the Evaluation of the Mechanical Properties of the Plantar Flexors by Using the Free Vibration Technique

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Additional information is available at the end of the chapter

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Abstract

The use of free vibration techniques to evaluate the responsiveness of a one-degree-of-freedom dynamic system linked to *musculo-articular stiffness* (MAS) of the plantar flexors has become an accepted procedure in scientific literature. However, the applicability and widespread use of this parameter have been limited thus far for different issues. On the one hand, the measurement of this parameter requires a noninvasive, nonstress laboratory test, which implies the use of appropriate in-lab infrastructure, ad hoc mechanical devices, and specific signal sensing units. On the other hand, it requires an efficient treatment and processing of the signal data obtained from laboratory tests through different signal filtering techniques and mathematical transformations. In the present manuscript, the fundamentals of the free vibration technique, the measurement device, the adjustment procedure, and finally the software based on java platform are presented in order to show the applicability of the MAS as parameter to evaluate the functional response of one subject based on his mechanical response of the lower part of the body once the whole procedure is addressed and controlled to ensure the reproducibility and the reliability of the test.

Keywords: muscle-tendon unit (MTU), musculo-articular stiffness (MAS), ankle joint, software

1. Introduction

Currently, there are many procedures to evaluate the functional response of one subject based on the theoretical performance of the lower part of the body [1, 2]. In this sense,

biomechanics use different procedures to measure the response of the subject and more specifically in relation to the mechanical response of the muscle. For instance, variations of jump (SJ (squat jump), CMJ (countermovement jump), and DJ (drop jump)) [3] measures, with contact platform or with dynamometric platforms, give information that goes from the elasticity index [1, 4] (general concept that encompasses many elements such as articulation and agonist and antagonist muscles) up to force-velocity curves [5].

Another way to analyze the functional response of the subject from the mechanical response of the muscle through a theoretical model is to resemble the behavior of the muscle to a mechanical model whose variables are known and "easy" to measure through equations that describe that behavior. These equations must consider all the physiological variables associated with it. These variables must go from the structure and the elements that are made of it, taking into account the viscoelastic properties of these elements and the innervation, to the theory or model that justifies the capacity to produce tension (muscular contraction). The latter is in intimate relation with all the other variables.

The elasticity of muscle fibers and tendon fibers plays a very important role in improving the effectiveness and efficiency of human performance. Muscles and tendons have a mechanical behavior very similar to a simple spring, and therefore, their response can be defined by a simple elastic model based on muscle-tendon unit (MTU) [6]. A simple way to represent this model is shown in **Figure 1**.

This figure shows (in a simplified way) the different components that can join in the mechanical response where the serial elastic component (SEC) represents the elastic component in series, the contractile component represents the actin and myosin cross ridge structures (CC), and PEC represents the elastic component in parallel.

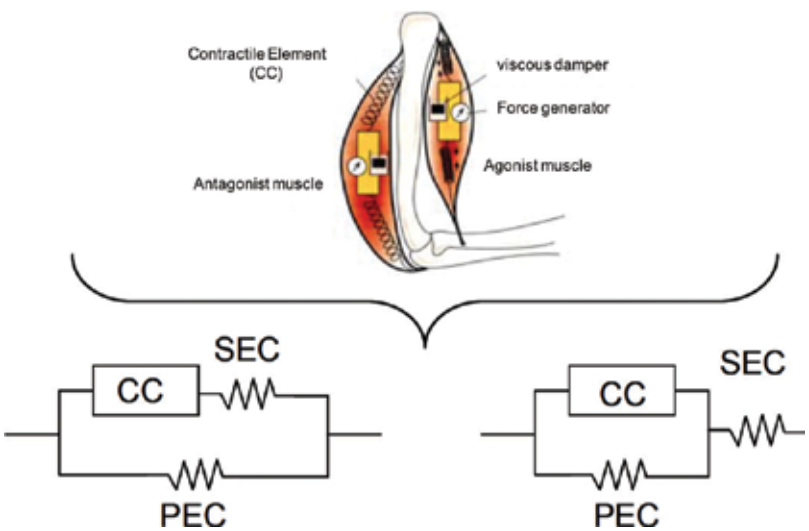

Figure 1. Schemes of MTU based on springs that represent the behavior of the muscles and tendons. CC, contractile component; SEC, serial elastic component; and PEC, parallel elastic component.

It is important to notice that, to have a direct correlation between the functional response of the subject (necessary in the movements of the daily life and in the sports field) and the viscoelastic parameters of the MTU, this MTU has to play an important role in the development of movements or displacements. For this proposal, the MTU chosen to be analyzed in the laboratory has been the plantar flexor muscles (in particular triceps surae MTU).

This MTU is the main one involved in plantar flexion movement. The plantar flexion is a phase of gait biomechanics and is therefore present in all movements in which displacement has to be carried out.

Therefore, the stiffness parameter is a very important factor related to muscle function [7, 8], to general sport performance [9, 10], and in particular to the performance during fast and slow stretch-shortening cycles (SSC) [8, 10–12].

The measurement of the mechanical properties (mainly stiffness) of MTU is widely reported in literature. In the present work, the procedure based on the free vibration technique will be followed and used.

The applications of the above methods (free vibration techniques) to obtain the stiffness of the MTU gave rise to the consistent use of the term musculo-articular stiffness (MAS) (henceforth k) [12]. MAS is a global measure of stiffness that incorporates not only the muscle-tendon structure but also the skin, ligaments, and articular surfaces [13]. Various assessments have demonstrated that MAS is a relevant parameter; higher MAS values are associated with superior muscular performance (e.g., [8, 14, 15]) and higher levels of functional capacity [16, 17].

The stiffness value (k) obtained from the experiments will depend on the procedure used to make the measurements, the comparison of these dependences being difficult and not being within the scope of the present work. Some of the proposed procedures measuring k, associated with the triceps surae, are based on the free vibration technique [14, 16, 18–22]. Among these proposals, in Babic and Lenarcic [19], the oscillation is rotational (rotation of the foot around the ankle articulation), while in the other proposals, the oscillation is associated with the vertical displacement of the lower part of the leg.

So far there are no tools that integrate the different variables that are required to be applicable and therefore can make the widespread use of MAS. In this sense, the following requirements have to be met: On the one hand, a noninvasive and nonstress laboratory test is required. This implies the use of adequate infrastructure in the laboratory, ad hoc mechanical devices, and specific units or devices for signal detection [23]. On the other hand, efficient treatment and processing of signal data obtained from laboratory studies are required through different signal filtering techniques, mathematical transformations, and the use of several software systems that must be integrated into the same tool.

In this chapter, a new software "FLEXOR" is presented as an integrated software solution that implements different aspects as signal processing, data management methods, algorithms, and flexible functionalities to support different adjustments. Researchers and trainers can evaluate the functional response of one subject from the mechanical response based on stiffness (i.e., MAS) of plantar flexor muscle-tendon units (MTU) while enabling the trial and error experimentation with different adjustment parameters and without using different software applications.

In this sense, FLEXOR improves the efficiency and effectiveness of the MAS analysis procedure, integrating all phases of the acquisition, processing, and postprocessing of the signal received from sensing devices in a timely manner.

2. Fundamentals

To measure the mechanical properties of the muscle-tendon unit, associated with the ankle joint, an in vivo test will be carried out. A device, specifically conceived for this purpose, has been manufactured to induce an oscillation in the lower limb of the leg. By means of an impact of controlled energy, a damped free oscillation is generated, and this oscillation is controlled by the viscoelastic mechanical properties of the triceps surae (Achilles tendon + soleus + gastrocnemius).

The initial record obtained by the device is the force measured during the oscillation by means of a load cell placed below the foot. This experimental record will be compared with the analytical equation of a one-degree-of-freedom system which is being assumed for the behavior of the oscillating part of the body. The parameters defining this oscillating system will be obtained by a least squares adjustment between the experimental record and the analytical function. The quality of this adjustment will be measured by using the regression coefficient parameter (R^2).

The corresponding theoretical models and the least squares fitting procedure are described in detail as follows.

The measurement device has been developed from a previous proposal [18] that uses the free vibration techniques, and this has been detailed in [20]. In the present manuscript, the one-degree damped system is obtained from the vertical displacement of the shank, which will be used as the reference equation of motion. This vertical displacement will be accompanied by rotations of the foot and of the upper leg. Since the frontal part of the foot is simply supported by a plate, the vertical displacement considered in the measurement involves the rotation of the foot around the ankle joint.

The measurement device developed and patented (see **Figure 2**) includes the following main parts to ensure the reproducibility and reliability of the test (These two aspects have been addressed in [24]):

1. Load cell (OMEGA LCM501-10 K; 1000 Hz) registered the reaction force during the oscillation. The load cell data acquisition frequency of 1 KHz granted a satisfactory sampling of experimental data. The load capacity of 1500 N is adequate for the typical force values to be measured in the experiments.
2. The impact necessary to obtain the expected response is generated by the free fall of a known mass and always constant from the same height. In this sense, the same energy is always applied, generating the same impact force. Therefore, the mass M_w causes the vertical movement of the lower leg as a one-degree-of-freedom system. It should

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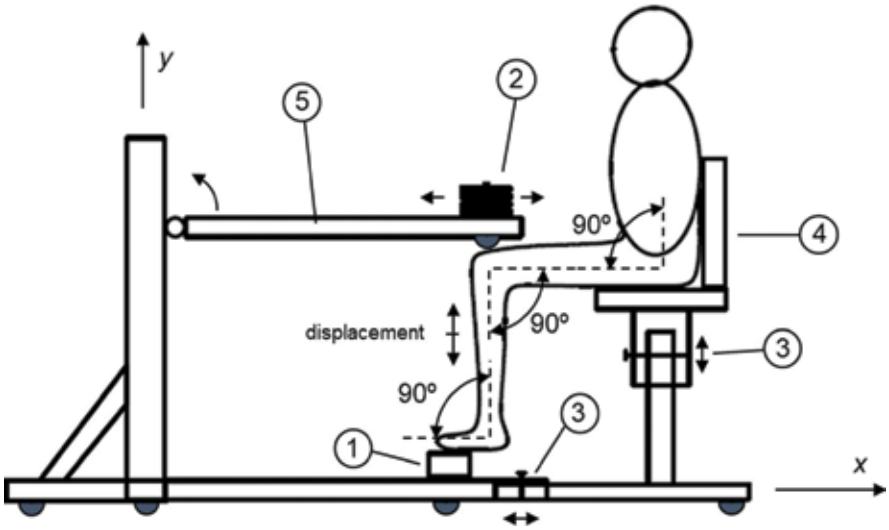

Figure 2. Schematic diagram of the measurement device developed for determining MAS linked to the ankle joint.

be noted that the total oscillating mass M is actually equal to the sum of M_w and the one-degree-of-freedom equivalent mass of the lower limb.

3. The regulation of these two elements (depth and height of the seat) allows the right position of the tested subject. Both degrees of freedom will allow to ensure the neutral position of the knee and 90° of hip and ankle joints.

4. In order to obtain the best response of the system, ensuring the vertical displacement of the shank and avoiding any horizontal displacement at the sagittal plane, a vertical backseat has been designed. Any movement of the head or shoulder in the sagittal plane can modify the response of the system. The subject must keep the position during the test in order not to induce pressure variations.

5. The loading system has been designed to facilitate the development of the test with different loads with different anthropometric features of the tested subject.

Once the impact is applied, the total mass *M* (i.e., the concentrated M_w plus the mass of the lower leg and the one-degree-of-freedom equivalent mass of the lower limb) starts to oscillate vertically (see **Figure 2**). During the perturbation, an arbitrary intermediate position for this movement is displayed in the sagittal plane (see **Figure 3**).

L represents the length of the lower leg, *R* is the moment arm of the second metatarsal head, and *r* is the Achilles tendon moment arm (both in the sagittal plane).

From the classical Hill's model, the MTU was schematized by means of a spring of stiffness *k* and a damper of constant *c* [25].

The mass (*M*) in **Figure 3** represents the total one-degree-of-freedom equivalent mass involved in the movement.

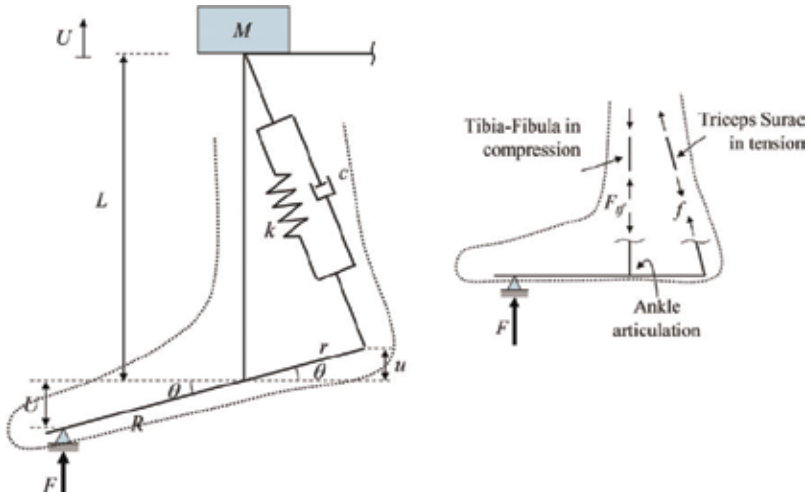

Figure 3. Diagram of the forces generated during the perturbation. (a) Simplified scheme of an arbitrary position taken in the vibration process. (b) Equilibrium of forces generated at the ankle joint.

The displacements U and u indicated in **Figure 3** are related by means of

$$U = \frac{R}{r}u \tag{1}$$

The equilibrium of forces stated around the ankle joint is displayed in **Figure 3**: the force F_{tf} keeps the tibia-fibula set in compression, while the force f keeps the plantar flexor muscles in tension. From the condition of dynamic equilibrium of the forces schematized in **Figure 3** with respect to the ankle articulation, it follows

$$\left(I + m_f r_G^2\right)\frac{d^2\theta}{dt^2} = FR\cos\theta - fr\cos\theta \tag{2}$$

θ is the angle (**Figure 3**) defining the instantaneous position of the foot, I is the momentum of inertia of the foot with respect to its center of gravity, m_f is the mass of the foot involved in the movement, and r_G is the distance between the center of gravity of the foot and the center of rotation. The force corresponding to the weight of the leg and concentrated mass does not produce moment with respect to the axis of rotation.

The values of parameters in the left-hand side of Eq. (2) were estimated from [26]; since these terms are much smaller than their counterpart for the right-hand side, Eq. (2) reduces to

$$FR = fr \tag{3}$$

The above equation allows the value of the force f passing through the line of action of the MTU to be obtained once the value of the reaction force F is measured by the load cell and the distances R and r are precisely determined for the tested foot.

The system shown in **Figure 3** includes two coupled degrees of freedom: the rotation around the ankle joint and the vertical displacement of the vibrating mass. Since the tibia-fibula set was assumed to be infinitely rigid, the vertical displacement of the mass M coincided with the vertical displacement of the ankle rotation point.

By taking as reference the configuration of the system including the external weight, the dynamic equilibrium condition for the total mass M, after the impact, can be expressed as

$$M\ddot{U} = -KU - C\dot{U} \tag{4}$$

By disaggregating the system, it can be written as

$$F = -KU - C\dot{U}\left(= M\ddot{U}\right) \tag{5}$$

The general solution of the differential Eq. (4) written for an underdamped system is

$$U(t) = e^{-\xi\omega t}(A\sin\omega_D t + B\cos\omega_D t) \tag{6}$$

where the constants A and B are determined from the boundary conditions of the problem.

The damping factor ξ is defined as

$$\xi = \frac{C}{C_c} = \frac{C}{2M\omega} \tag{7}$$

where C is the damping of the system, C_c is the critical damping of the system, M is the total mass involved in the movement, and ω is the natural frequency of the vibrating system.

The frequency of vibration ω_D of the damped system is

$$\omega_D = \omega\sqrt{1-\xi^2} \tag{8}$$

By defining the parameter γ as

$$\gamma = \xi\omega = \frac{C}{2M} \tag{9}$$

ω_D can be expressed as follows:

$$\omega_D^2 = \omega^2 - \gamma^2 \tag{10}$$

The general expression of displacement (6) can be substituted in the equation of dynamic equilibrium (5). It is thus possible to express the total force F acting on the mass M as

$$F = \left(M\ddot{U}\right) = e^{-\gamma t}(A_F\sin\omega_D t + B_F\cos\omega_D t) \tag{11}$$

The total force F_m is the sum of F (load cell) plus the action of the gravity:

$$F_m = F + M_s g = e^{-\gamma t}(A_F \sin \omega_D t + B_F \cos \omega_D t) + M_s g \tag{12}$$

Once these unknown parameters are determined, the values of apparent stiffness K and damping C of the whole system can be determined as follows:

$$K = M\left(\omega_D^2 + \gamma^2\right) \tag{13}$$

$$C = 2\gamma M \tag{14}$$

Parameters K and C can be related to the apparent stiffness k and damping c of the MTU. For that purpose, the condition of dynamic equilibrium can be written also for the MTU as follows:

$$f = -ku - c\dot{u} \tag{15}$$

By substituting Eqs. (1) and (3) in Eq. (5) and rearranging the expression, it follows

$$f = -\left(\frac{R}{r}\right)^2 Ku - \left(\frac{R}{r}\right)^2 C\dot{u} \tag{16}$$

Since Eqs. (15) and (16) are equivalent, all terms contained in these expressions must coincide. The following conditions can hence be obtained:

$$k = \left(\frac{R}{r}\right)^2 K, \quad c = \left(\frac{R}{r}\right)^2 C \tag{17}$$

An important aspect from the above-described model is the precise determination of the values of r and R for the tested subject.

The separation of the muscle tissue and Achilles tendon components from the global apparent value of the stiffness can be done, following Hill's model. The spring (that corresponds to the global response) includes the spring associated with the elastic behavior of the Achilles tendon (constant value of stiffness) and set of springs in parallel (in accordance with Hill's model [27]), in series with the Achilles tendon, representing the elastic behavior of the muscle.

While the Achilles tendon is assumed to have a constant value of the stiffness (k_t), the soleus is assumed to have a stiffness (k_m) which is proportional to the load that is being transferred by the system. Thus, the total stiffness of the soleus (k_m) can be obtained from a unitary stiffness value (k_{ss}) multiplied by the total load (f) passing through the MTU:

$$k_m = k_{ss} \cdot f \tag{18}$$

The relationship between the equivalent global stiffness (k) and the individual stiffnesses (k_{ss} and k_t) can be easily obtained from **Figure 3**, with two springs in series. On the one hand, for the apparent TS system, the elongation and the associated force are related by the equivalent stiffness k by means of

$$u(k) = \frac{f}{k} \tag{19}$$

On the other hand, for the components in series, both with the same force (f), the following relation applies:

$$u(k_t, k_m) = u(k_t) + u(k_m) = \frac{f}{k_t} + \frac{f}{k_m} \tag{20}$$

Identifying displacements in Eqs. (19) and (20), in order to have an equivalent behavior, an expression of k in terms of its individual constituents (k_m and k_t) can be easily obtained, and using Eq. (18) in terms of (k_{ss} and k_t),

$$k = \frac{k_t k_m}{k_t + k_m} = \frac{k_t k_{ss} f}{k_t + k_{ss} f} \tag{21}$$

In Eq. (21) k and f are considered known. The unknowns in Eq. (21) are the stiffness of the Achilles tendon and the unit stiffness of the soleus, respectively, k_t and k_{ss}. They will be evaluated by means of least squares fitting between experimental data and Eq. (21).

It is important to stress that k_t and k_{ss} are unknowns of a different nature. While in the Achilles tendon, k_t is a real stiffness value (measured in force/length, e.g., kN/m) k_{ss} represents the stiffness per unit load in the soleus (e.g., $(kN/m)/kN$ or simply m^{-1}). For a better physical understanding of the parameters k_t and k_{ss}, **Figure 7** represents Eq. (21), showing the nonlinear dependence of the total stiffness of the MTU (k) on the total load (f) and a saturation level for high values of f.

The stiffness per unit load in the soleus k_{ss} represents the slope of the curve at the origin

$$k_{ss} = \lim_{f \to 0} \frac{dk(f)}{df}, \tag{22}$$

while the Achilles tendon stiffness k_t represents the horizontal asymptote of the curve for high values of the total force f:

$$k_t = \lim_{f \to \infty} k(f) \tag{23}$$

With the two elastic elements (Achilles tendon and soleus) in series, the lower stiffness is the one that controls the apparent stiffness of the TS. With low values of the total transmitted force f, the stiffness of the soleus ($k_{ss} \cdot f$) is lower than the stiffness of the Achilles tendon k_t. Thus, the total stiffness k is controlled by the stiffness of the soleus. By contrast, at higher values of f, the stiffness of the soleus ($k_{ss} \cdot f$) is much higher than the constant value of the Achilles tendon k_t. Thus, the total stiffness k is now controlled by the stiffness of the Achilles tendon k_t. Finding experimental results close to the horizontal asymptote depends on the total stiffness that can be developed by the soleus. This fact is important as an accurate determination of both values (k_t and k_{ss}) should be carried out, having experimental results for low and high values of f.

3. Application (adjustment procedure)

As an example of the whole procedure of measurement and postprocessing of the raw experimental data, a brief description of the process is summarized in what follows from a practical point of view.

First of all, using the device manufactured for the test (see **Figure 4**) applying different external loads on the knee of the subject and after an impact of controlled energy, a load versus time record is obtained. Different loads (placed on the knee of the subject) are used to obtain the full response of the MTU. A typical record is shown below (see **Figure 5**). Notice that the oscillation of the perturbation is only around 1 second in length. This is the value recorded at the load cell, which is placed under the second metatarsal of the foot.

The equation representing the one-degree-of-freedom system, previously introduced in Section 1 (Eq. 11), can be used to fit the experimental part of the curve (in the oscillation range) by

Figure 4. Pictures of the measuring device that integrates the different elements (regulation systems, load cell, and integrated software) to obtain the mechanical properties of the plantar flexors by means of the free vibration technique.

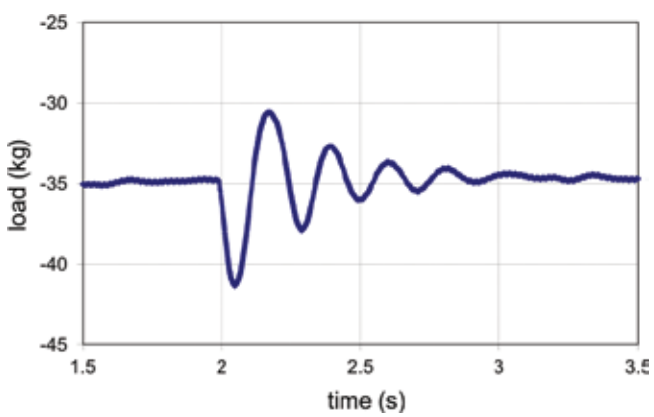

Figure 5. Force versus time record for a single test.

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means of a least squares procedure to determine the five parameters included in this equation (A_F, B_F, ω_D, M, γ).

This fitting procedure is not straightforward, and several aspects should be taken into account for an accurate determination of the parameters. Three of the five parameters (ω_D, M, γ) can be easily initially estimated by simple observation of the curve, because they are associated with the frequency, stationary mass, and damping coefficient, respectively. Once this initial estimation is done, the precise determination of the complete set of values is easily carried out by any standard multivariable least squares routine. For further details of the procedure, see [20], where sensitivity analysis was also performed to check the robustness of the fitting procedure to avoid local minimum solutions. In this first step of the complete procedure, some care has also to be taken when selecting the range of the record to be fitted. The longer the record, the better, but data just after the initiation of the oscillation (just after the impact) have to be discarded and also data near the end of the oscillation need also to be discarded, as the noise is of the same amplitude that the amplitude of the oscillation.

The software, implemented by the authors for the automatic processing of the complete procedure, takes into account all these details for a robust determination of the set of parameters. The software implementation will be briefly summarized at the end of this section.

The experimental behavior of the lower limb of the leg can be mathematically modeled as a single-degree damped system; some examples of the fitting procedure are shown in **Figure 6**. In **Figure 6b**, a secondary higher frequency can be observed, which is due to the natural frequency oscillation of the metallic structure of the device used to carry out the test. Care must also be paid to this fact to ensure that this natural frequency is, at least, one order of magnitude higher than the natural frequency of the physiological part of the oscillation.

For each one of the curves, a pair of values (F, K), representing the average force and the global stiffness of the oscillating system (the whole lower limb and accessories), can be, respectively, determined using Eqs. (11) and (13). Using the moment arm lengths of the forefoot (R) and rearfoot (r) and the moment equilibrium equations given in (Eqs. (16) and (17)), the force (f) and the stiffness (k) of the MTU can be obtained.

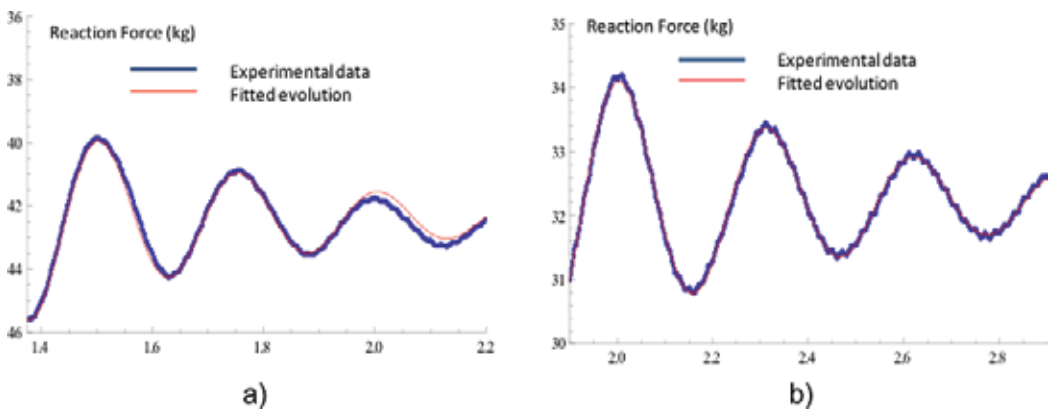

Figure 6. Examples of fitted curves with different applied loads. (a) Applied load 30 kg. (b) Applied load 20 kg.

Taking into account that the stiffness of the Achilles tendon can be assumed to remain almost constant with the load passing through it, and that the stiffness of the soleus is a function of the load passing along the muscle, several different weights have to be used to completely determine the mechanical behavior of the system. This behavior, together with the fact that each load is tested more than once (to avoid high dispersion of the results), generates several curves that have to be postprocessed.

This process is tedious, and error-prone, if made manually. The developed software takes all curves and processes all of them in a single click, including quality evaluation of the fitting procedure by means of the regression coefficient parameter (R^2) arising from the least squares procedure.

Once the complete set of tests are performed and each one has been processed to obtain the five parameters, a new cloud of processed data (f,k) is available, as schematically observed in **Figure 7**. A new mathematical model (see Eq. 21) describes the mechanical behavior of the triceps surae varying with the load passing along it. A new least squares fitting can be done to determine the stiffness of the Achilles tendon (k_t) and the unitary stiffness of the soleus (k_{ss}). This time, only two parameters are involved in the fitting process, but it is important to notice that each pair of data (f,k) is the result of a previous fitting procedure, including some uncertainty in their determination, as the regression coefficient is less than one ($R^2 < 1$).

With respect to this quality indicator (R^2), it is also important to stress (see **Figure 7**) that the value of R^2 changes if all individual values are taken into account (R^2 = 0.86) or the fitting process is carried out with the average values for each load (R^2 = 0.95), although the fitted curve is almost coincident using both alternatives. In both cases the regression coefficient is very close to unity, which means that the mathematical model in this second step of the process also accurately reproduces the physical behavior of the physiological system.

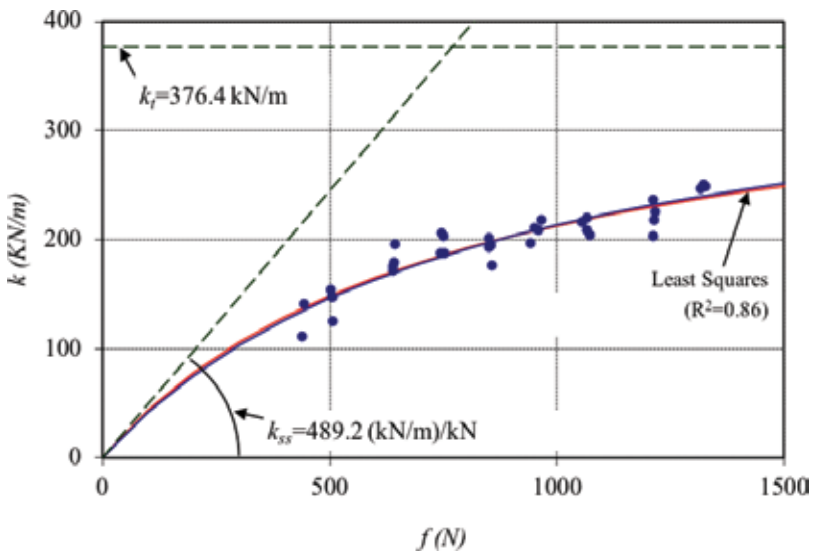

Figure 7. Example of the second fitting procedure.

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The analyses of the quality of the adjustment procedure for different subjects and different days have been carried out in the previous work [24].

The Achilles tendon stiffness value is associated with the horizontal asymptote of the curve, while the unitary stiffness of the soleus is given by the slope of the curve when $f \rightarrow 0$ (see **Figure 7**).

The relationship between the stiffness of the triceps surae (k) and the stiffness of the Achilles tendon (k_t) and the unitary stiffness of the soleus (k_{ss}) can be easily manipulated (taking the compliance (k^{-1}) instead of the stiffness (k) to give a linear relationship, as can be observed (see **Figure 8**).

With this linear relationship, different robust procedures for linear regression can be used. In [28], the authors used up to four different procedures for linear regression, to check the influence of the fitting method on the results.

This second adjustment step, done by the cloud of points coming from the results of the first test (and first fitting procedure), finally gives the desired mechanical properties: stiffness of the Achilles tendon (k_t) and the unitary stiffness of the soleus (k_{ss}).

As a summary of the complete experimental process, and previously to introduce the implementation of the developed software to automatize the postprocessing of data, the steps of the process are:

1. The subject is placed in the testing device, and with a certain weight on the knee, and with an impact of controlled energy (on the knee), the lower limb oscillates, and a force versus time record is obtained (see **Figure 5**).
2. This record is repeated for each weight (four or five times).
3. The weight on the knee is changed, and four or five individual tests are repeated.
4. For each record, a first fitting procedure is carried out (see **Figure 6**), obtaining the five parameters (A_F, B_F,ω_D, M, γ).
5. With these parameters the pairs (F, K) are obtained, and using the moment arm distances of the foot (f,k) are finally calculated, one pair (f,k) for each test.

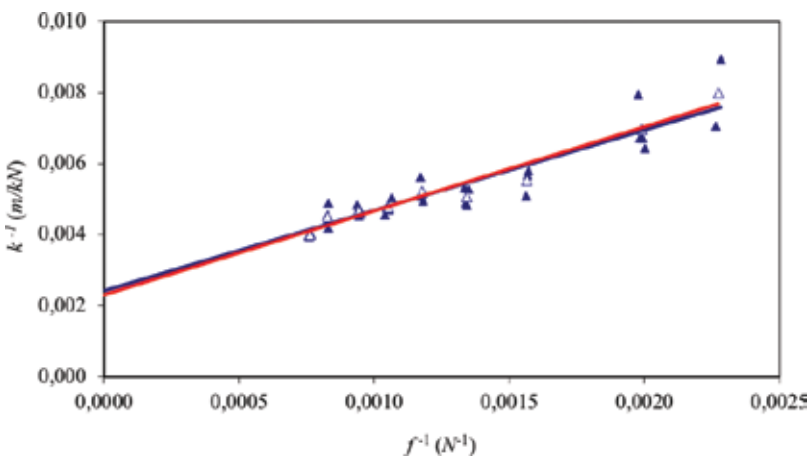

Figure 8. Linear dependency of compliances.

6. With all pairs (f,k), a second fitting adjustment is carried out, using stiffness (see **Figure 7**) or using the compliances (see **Figure 8**). This second least squares fitting procedure gives the desired values of the Achilles tendon stiffness (k_t) and the unitary stiffness of the muscle (k_{ss}).

All this experimental procedure and the associated postprocessing of results are tedious, as different hardware and software are involved in the different steps:

- For the initial record of the force versus time data, an acquisition software (e.g., LabVIEW) and hardware need to be used, taking into account all aspects previously mentioned to try to guaranty the quality of the record.
- These data have to be prepared and introduced in a mathematical software (e.g., Mathematica, MATLAB, etc.) to perform the first fitting adjustment.
- After the manual postprocessing of all tests, a second file is prepared, which also needs to be fitted with the second adjustment procedure.
- All manipulations between software are being done manually with a certain probability of errors.

4. Software FLEXOR

To avoid all these technician manipulations, a software has been implemented to perform the acquisition and postprocessing of data in a single software.

Figure 9 shows an example of the first-phase fitting (red curve is the experimental data and blue line the representation of the mathematical equation), which is the most time-consuming. This window has all control parameters needed to optimize the time for data processing. The software can read online the load cell (little window at the top right part of the panel software) (see **Figure 9**) and saves all records with a format which allows to recover the different projects to perform additional calculations.

All tests for the different load range used (0–50 kg) in one project are displayed on the left side of the screenshot. All of them have the approval criterion (green check symbol) of the software, which means that the fitting parameter, the regression coefficient, $R^2 > 0.9$. The details of the window range adjustment and the details of the parameters used are shown on the right side of the screenshot. In the present case, all tests carried out give rise to excellent adjustments. This procedure, which was previously carried out manually, is now performed with a single mouse click, the software analyzing all introduced records sequentially.

As an example of the potential of the software, the analyst can change manually one or more parameters of the adjustment. In some cases, when the experimental data have not enough quality, the analyst can manually modify any of the five parameters or even the window of adjustment to obtain the best result (R^2 values close to the unit).

Finally, the second phase of the adjustment is displayed, in the same window (not shown in **Figure 9**), and the cloud of points generated from the first phase of the adjustment and final results for the Achilles tendon stiffness and soleus unitary stiffness can be displayed.

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Figure 9. Software view.

After performing all calculations, the software makes a report with all data and stores the files for future manipulations.

The software has a flexible design, in order to be adaptable to future requirements, adding new functionalities through a software component-based approach, as well as to provide the information generated in the different studies in an interoperable way, using JSON technology. This enables multi-stakeholder scenarios, where different types of analysts with different FLEXOR installations (e.g., different application servers, platforms, and technologies) are able to conduct joint studies in a remote way, just exchanging FLEXOR proprietary files which represents studies (*.fxs, *.fxp).

So far, several studies have been conducted in the lab to analyze the reproducibility of the results comparing the one used in previous procedures and the results obtained by the software. To carry out this comparison, load cell raw data (files) from previous studies conducted using the former procedure have been used. Each file contains the list of points (force, time) that comes from the load cell. When the file is imported in the new software, automatically, it parses the file into a sample and calculates the first-phase adjustment. Importing the list of files that corresponds to a project obtained from one subject, the same study can be simulated (and the procedure) through the software. This approach allows to validate that the software works in a proper way, checking if the results are equal to the previous studies conducted.

The software and the mechanical device conceived for the tests are a practical tool for technicians, researchers, and professionals to make quick and reliable evaluations of the mechanical properties of the muscle-tendon units of subjects. These mechanical properties have a direct influence on the sport performance and thus becoming a very interesting tool to be used in different applications, from rehabilitation to evaluation of sport performance, etc. The software is prepared to be used in any platform in a simple way.

5. Conclusions

In the present work, the mechanical properties (mainly stiffness) of the musculo-articular stiffness (MAS) have been obtained by means of the free vibration technique.

For this objective, a measurement device has been conceived and manufactured. This device allows to carry out the test for subjects with different anthropometric characteristics and ensures a high level of reproducibility and reliability of the tests.

The complete postprocessing of the experimental data has been done according to the physiological models of the muscle-tendon unit (MTU). The whole process has been deeply analyzed and implemented in the calculations since this is very sensitive to the influence of other variables being a key point for the calculation of the desired parameter. On the one hand, the reproducibility and the reliability of the MAS depend on the measurement device developed to ensure always the same response of the subject. On the other hand, the high levels of precision in the adjustment process are required as well.

Finally, the study of the mechanical response of the MTU to evaluate the functional response of the subject depends on the applicability of the parameter. In this sense, to facilitate the postprocessing of the experimental data, a software (FLEXOR) has been implemented allowing the adjustment of all variables and an agile data management.

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The development and implementation of new technology devices to help professionals, athletes, and non-athletes improve their physical fitness, performance, health, and well-being have emerged in the last few years. This book briefly overviews the current state of the art in technology applied to sports, providing examples, literature syntheses, and recent applications to sports, focused on the most important evidenced-based developments in this area. Attention is drawn to issues and unusual matters that may arise when it comes to technological innovation applied to sport. For the reader, this could be a different perspective on technological progress in physical activity.

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