Escola Superior de Saúde Atlântica

Degree in Physiotherapy

Research Project

Year 4

Academic Year 2023/2024

FINAL PROJECT

INTEREST OF A WHOLE-BODY PHOTOBIOMODULATION THERAPY ASSOCIATED WITH A CONVENTIONAL RECOVERY PROTOCOL COMPARED TO A CONVENTIONAL RECOVERY PROTOCOL ALONE ON POST-EXERTION PAIN AND MUSCLE PERFORMANCE IN ELITE AMATEUR FOOTBALLER

Student:

Enzo BRANDO (Essatla n° 772023103)

Memory Tutor:

Carole PUCCINI

Barcarena – June 2024

Escola Superior de Saúde Atlântica

Degree in Physiotherapy

Research Project

Year 4

Academic Year 2023/2024

FINAL PROJECT

INTEREST OF A WHOLE-BODY PHOTOBIOMODULATION THERAPY ASSOCIATED WITH A CONVENTIONAL RECOVERY PROTOCOL COMPARED TO A CONVENTIONAL RECOVERY PROTOCOL ALONE ON POST-EXERTION PAIN AND MUSCLE PERFORMANCE IN ELITE AMATEUR FOOTBALLER

Student:

Enzo BRANDO (Essatla n° 772023103)

Memory Tutor:

Carole PUCCINI

ACKNOWLEDGEMENTS

The completion of this research project was made possible by the help of several people to whom I would like to express my gratitude.

First of all, I would like to thank my supervisor, Mrs. PUCCINI Carole, for her patience, availability and trust throughout the writing of this research project. I would also like to thank her for her wise advice, which helped to stimulate my thinking. I would also like to express my sincere gratitude to all the teaching staff of ESSATLA University, as well as to the professional lecturers in charge of my course, who were able to pass on their knowledge and experience. Finally, I would like to thank my family, my partner and all those close to me for their unconditional support and encouragement throughout the realisation of my project.

To all these people I express my thanks, my respect and my gratitude.

ABSTRACT

Introduction: A source of discomfort, Delayed-Onset Muscle Soreness (DOMS), resulting from muscle microlesions known as Exercise-Induced Muscle Damage (EIMD), can occur after exercise in elite amateur footballers. Despite the variety of existing recovery techniques, there is no consensus in the literature and scientists highlight the need to identify the most effective recovery strategies. Whole-body Photobiomodulation Therapy (PBMT) seems particularly interesting in this area, despite the controversy and lack of scientific studies on the subject. From a synergistic point of view, it is worth asking whether the use of whole-body PBMT combined with a conventional recovery protocol has a significant impact on the post-exercise recovery of elite amateur footballers affected by EIMD.

Objective: The general objective of the study is to compare the effect of whole-body PBMT combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise recovery in elite amateur footballers affected by EIMD.

Methodology: This will be a prospective, quantitative, experimental study in the form of a randomised controlled trial. The study will be multicentric and will be carried out in the two "elite" clubs (“National 2” Championship) that responded positively to the proposal. Subjects will be selected according to inclusion and exclusion criteria. From the target population, random cluster sampling will make it possible to assign the first club to a conventional recovery protocol alone and the second club to a Whole-body PBM therapy combined with a conventional recovery protocol. They will be standardised and will follow a common training protocol, generating EIMDs. Data will be collected in a blinded process by independent assessors who will not know the group distribution. It will be carried out before the training protocol and 48 hours after training, when DOMS are described as being the most intense. The main evaluation criterion of the study will be the intensity of lower limb muscle pain, self-assessed using a digital Visual Analogue Scale (VAS). The secondary evaluation criteria will be the maximal muscular strength and power of the lower limbs generated during a vertical jump, measured by a "MyotestPRO®" accelerometer.

Conclusion: Thus, the study would make it possible to assess the effectiveness of whole-body PBMT in developing an optimal post-exercise recovery protocol that is accessible and follows the Evidence Based Practice (EBP) model in elite amateur footballers affected by EIMD. New perspectives could then be explored.

Key Words: Recovery / DOMS / Whole-body PBMT / EIMD / Amateur football.

SUMMARY

LIST OF ABBREVIATIONS

ATP: Adenosine Triphosphate.

BFR: Blood Flow Restriction.

COX: Cytochrome c-oxydase.

CK: Creatine Kinase.

CMJ: Counter Movement Jump.

CRP: C-Reactive Protein.

CWI: Cold Water Immersion.

CWT: Contrast Water Therapy.

DOMS: Delayed-Onset Muscle Soreness.

DOSS: Delayed-Onset Soft Siftness.

EIMD: Exercise-Induced Muscle Damage.

EBP: Evidence Based Practice.

FFF: French Football Fédération.

FIFA: Federation International of Football Associations.

IL-6: Interleukin-6.

LED: Light-Emitting Diode.

MCID: Minimum Clinically Important Difference.

NGF: Nerve Growth Factor.

NO: Nitric Oxide.

PBMT: Photobiomodulation Therapy.

ROS: Reactive Oxygen Species.

VAS: Visual Analogue Scale.

WBC: Whole Body Cryotherapy.

LIST OF FIGURES AND TABLES

INTRODUCTION

With nearly 291 million active players across the world, football occupies a dominant position in the global sporting landscape. In fact, a survey conducted in 2006 by the Federation International of Football Associations (FIFA) revealed that 4% of the world's population holds a football licence, confirming its position as the world's number one sport (Kunz, 2006). France is a prime example of this collective and social craze. According to a study carried out in 2013 by the “Foundation of Football” and the “Amateur Football League”, the country has over 2 million licensed players (representing 12% of all sports licences) and no less than 5 million unlicensed recreational players.

This popular sport, which has always aroused the interest and passion of millions of people, is not without its risks. A recent cohort study of English professional footballers found that muscle tension was the most common cause of injury, accounting for 41.2% of cases (Jones et al., 2019). These injuries affect the integrity of a team. On average, a group of 25 players can expect around 45 injuries per season, half of which will result in more than a week's absence (Ekstrand, 2007). Based on these findings, the scientific community has attempted to identify the various risk factors associated with football injuries. These factors include in particular: previous injuries, advanced age (Hägglund et al., 2013) and muscle fatigue linked to incomplete recovery (Nédelec et al., 2012).

Repeated mechanical stress over a prolonged period during training or competition induces micro-lesions in the muscle known as “Exercise-Induced Muscle Damage” (EIMD). They are the cause of Delayed-Onset Muscle Soreness (DOMS), more commonly known as "muscle soreness". Harmful to sportspeople, especially footballers, these painful muscle stiffnesses increase the risk of injury and have a negative impact on performance. In particular, muscle soreness can lead to muscle pain, a decrease in muscle strength and a reduction in the range of motion (Veqar & Imtiyaz, 2014).

In order to meet the sporting demands of their club, as well as the expectations and requirements of their professional activities outside of sport, elite amateur footballer need to be vigilant and rigorous about their recovery. In science, post-exercise recovery is defined as "*the return of the entire biological system to homeostasis without maladaptation*" (Soligard et al., 2016). However, although rest is an important part of the recovery process, a recent study has shown that 72 hours is not enough time for DOMS to disappear after a football match (Silva et al., 2018).

In this context, it is essential that scientists implement different protocols to optimise post-exercise recovery so that amateur footballers can maintain the intense pace of their daily lives. Researchers have therefore studied several options to improve sports recovery (medication, nutrition, active recovery, compression, cryotherapy, immersion techniques, stretching, etc.) obtaining heterogeneous results. Among them, massotherapy and immersion techniques such as Contrast Water Therapy (CWT) appear to be the most popular and effective treatments in football to reduce DOMS and improve sports performance (Ahokas et al., 2019; Dupuy et al., 2018; Nédelec et al., 2013). However, despite the wide range of recovery techniques described by the scientific community, there is a lack of consensus on the implementation of an optimal recovery protocol and differing opinions on the true effectiveness of some methods (Dupuy et al., 2018; Querido et al., 2022).

Always seeking to optimise the recovery of athletes by adding more evidence to this controversial literature, scientists have recently described the principle of Photobiomodulation Therapy (PBMT) on post-exercise recovery. PBMT is a light therapy that uses non-ionising light sources such as lasers, Light-Emitting Diodes (LEDs) and broadband light from the visible to the infrared spectrum. Also known as "phototherapy", it is a non-thermal process in which light interacts with chromophores, causing photophysical and photochemical reactions in different tissues to relieve pain, reduce inflammation and promote tissue regeneration (Leal-Junior et al., 2019). The literature suggests that PBMT may have a greater effect on post-exercise recovery if it targets the whole body. Researchers believe that the use of these devices (which are currently in development) would provide a real benefit by treating more target tissues in less time (Ghigiarelli et al., 2020). In addition, these studies note that there is a limited amount of work on this topic (whole-body therapy) and suggest that further research is needed to understand the impact on the athlete's performance and physiological recovery. In fact, the vast majority of current research on PBMT has used devices whose strategy is to treat isolated muscle groups locally, sometimes with controversial results (Forsey et al., 2023; Ghigiarelli et al., 2020). **Thus, does Whole-body PBMT combined with a conventional recovery protocol have a significant effect on post-exertion pain and muscle performance in elite amateur footballer affected by EIMD compared to a conventional recovery protocol alone ?**

This work would respond to the issues raised in the recent scientific literature. It would provide additional answers to the potential benefits of Whole-body PBMT combined with a conventional recovery protocol, while specifying its optimal application procedure. Furthermore, this project appears to be relevant as the scientific community is currently encouraging further research to identify effective strategies to improve recovery in athletes (Querido et al., 2022). On this topic, the literature also considers that it would be wise to study the implementation of a protocol combining several recovery techniques to assess whether synergistic phenomena occur (Dupuy et al., 2018). Finally, it would make it easier for elite clubs to decide whether or not to invest in these expensive recovery devices based on relevant results regarding the potential effectiveness of whole-body PBMT in this field.

The general objective of the study is to compare the effect of Whole-body PBMT combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise recovery in elite amateur footballers affected by EIMD. The study has several specific objectives. The specific objectives are to compare the effects of whole-body PBMT combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise pain intensity, muscle strength and power in elite amateur footballers affected by EIMD.

To this end, the prospective experimental study will be quantitative, controlled and multicentric. A blind evaluation will be carried out on elite amateur footballers at "National 2" level (4th level in France, corresponding to the highest amateur level). Cluster randomisation will be used to assign the conventional recovery protocol to the control group (1st club) and the whole-body PBM therapy combined with a conventional recovery protocol to the experimental group (2nd club). The main evaluation criterion of the study will be the intensity of lower limb muscle pain, self-assessed using a digital Visual Analogue Scale (VAS). The secondary evaluation criteria will be the maximal muscular strength and power of the lower limbs generated during a vertical jump and measured by a "MyotestPRO®" accelerometer.

This work is divided into several chapters. The first part is devoted to the introduction of the dissertation. The second part is dedicated to the theoretical framework, describing the general background of DOMS, the pathophysiological origin and the detrimental consequences of muscle soreness on the body, as well as a presentation of the different recovery strategies described in the scientific literature. The third part deals with the methodology of the study and includes: objectives, study design and plan, population and sample characterisation, data collection instruments, study variables and hypotheses, as well as project implementation procedures. The final chapter presents the critical reflections and conclusions of this work, in order to analyse the strengths and limitations of the project. Finally, the thesis concludes by presenting the bibliographical references studied.

THEORETICAL FRAMWORK

1. « DOMS » : Diseases causing discomfort

1.1 Definition and generalities about DOMS

Repeated mechanical stress during physical activity causes muscle microlesions, known as Exercise-Induced Muscle Damage (EIMD). These are at the origin of Delayed-Onset Muscle Soreness (DOMS), which is an integral part of intrinsic muscle lesion pathologies (Mueller-Wohlfahrt et al., 2013). From a clinical point of view, muscle soreness is a true post-exertional inflammatory muscle syndrome, characterised by diffuse muscle sensitivity, with painful palpation concentrated precisely at the distal myotendinous junction or in the most pinnate part of the muscle (Cohen & Cantecorp, 2011; Coudreuse et al., 2007). In terms of symptomatology, pain in the lower limb is mainly felt in the quadriceps, but can also affect the hamstrings and the triceps surae (Coudreuse et al., 2004).

DOMS appears gradually over a period of 12 to 48 hours following intense and/or unusual, predominantly eccentric work. Usually present on resumption of sporting activity or when there is a change in the type of training, these muscular disorders reach a painful peak between 48 and 72 hours, then diminish to disappear 5 to 7 days later (Coudreuse et al., 2007; Valle et al., 2014). Thus, sports subjects affected by DOMS may feel muscle pain at rest, during passive stretching and during isometric or dynamic contractions, with pain increased by eccentric work (Cohen & Cantecorp, 2011).

1.2 Pathophysiological origins of DOMS

Although there is not always a clear consensus on the cause of DOMS, unusual muscle work of eccentric origin seems to be the most credible mechanism in the onset of muscle soreness (Cheung et al., 2003; Nelson, 2013; Heiss et al., 2019). Indeed, this contraction regime induces mechanical stress and can cause microlesional structural damage to the Z-disc, sarcolemma, basal lamina, connective tissue, contractile elements and cytoskeleton (Koch et al., 2014), leading to increased sarcomere overstretching.

Furthermore, the existing correlation between eccentric work and the development of DOMS can be explained by a majority recruitment of type II fibres, which are composed of an extracellular matrix and Z band that are less developed and narrower than type I fibres (Connolly et al., 2003). However, the micro lesions caused by eccentric contractions occur directly during the exercise. Consequently, they don't fully explain the presence of muscle soreness, which gradually appears over the following 12 to 48 hours. Based on the pathophysiological basis, some authors explain that treatment considerations should also focus on the inflammatory responses stimulated by the injured musculotendinous system (Heiss et al., 2019).

The inflammation required to resolve EIMD may be largely responsible for the development of DOMS. Lesion damages disrupt the homeostasis of the damaged fibres and are accompanied by an accumulation of calcium, which activates the proteolytic enzymes responsible for Z-band degradation. Thus, the accumulation of interstitial fluid, the formation of intramuscular oedema and the presence of pro-inflammatory substances such as Nerve Growth Factors (NGF), histamine, bradykinin and prostaglandins have been described as responsible for the nociceptive activation of type III and IV nerve fibres and the algesic symptom (Nie et al., 2009; Kim & Lee, 2014). Type IV fibres cause the dull and diffuse pain, characteristic of DOMS.

Furthermore, a study published in 2020 put forward the hypothesis of axonopathy (pathology of the axon) caused by acute compression of the nerve endings of the muscle spindle. This would be caused by the superimposition of compression when repetitive eccentric contractions are performed under cognitive demand (Sonkodi et al., 2020). Finally, the latest scientific theories suggest that the extra muscular connective tissue and particulary deep fascia (Annex A) plays a dominant role in the pathogenesis of DOMS. Indeed, the tensile forces associated with eccentric contraction can cause microtears and inflammation of the deep fascia which, according to the research, appears to be more sensitive to pain than muscle following chemical, thermal, electrical and mechanical irritation. Nevertheless, the cause-effect relationship concerning this Delayed-Onset Soft Stiffness (DOSS) has not yet been clearly established (Tenberg et al., 2022; Wilke & Behringer, 2021).

1.3 Pathophysiological consequences of DOMS

According to Byrne et al (2004), soreness has a negative impact on certain performance criteria such as sprinting, muscular strength and jump performance. Furthermore, the onset of DOMS is the cause of several dysfunctions (Pearcey et al., 2015): A decrease in proprioceptive function, a disturbed sense of joint position, a reduction in joint amplitude, as well as a decrease in muscle strength. It is accentuated in the 24 to 48 hours after exercise and, along with pain, seems to be the most frequently cited consequence (Veqar & Imtyaz, 2014; Heiss et al., 2019). Finally, recruitment patterns may be altered. These compensatory mechanisms impair athletic performance, but can also increase the risk of injury (Cheung et al., 2003). All of these impairments to muscle function and joint mechanics are therefore added to the **delayed-onset algic symptom** described previously (Annex B). From a biological point of view, scientists have reported increased Creatine Kinase (CK) activity in blood plasma, which is closely associated with DOMS. Other biomarkers, such as Interleukin-6 (IL-6) and C-Reactive Protein (CRP), can be assessed in the inflammatory process, but the analysis of these parameters should be relativised as they can influence many physiological processes even in the absence of inflammation (Hotfiel et al., 2018).

2. Description of therapeutic methods / techniques

2.1 Medicinal strategies and metabolic processes

Oral medication, in particular non-steroidal anti-inflammatory drugs, aim to improve the management of DOMS and muscle injuries. However, this inflammatory inhibition would be at the origin of the negative effects on muscle regeneration (Heiss et al., 2019; Paulsen et al., 2012). Concerning nutritional strategies, the post-exercise ingestion of carbohydrates and proteins with a high glycaemic index would accentuate the recovery process in order to improve muscle function and reduce soreness (Nédélec et al., 2013). Furthermore, the role of hydration is to restore water loss and facilitate thermoregulation to maintain optimal sports performance (Thomas et al., 2016). Finally, sleep quality remains essential, as its alteration increases pain sensitivity after acute soft tissue injury (Palsson et al., 2023).

2.2 Active recovery strategies

The principle of active recovery aims to facilitate the elimination of metabolic waste; however, it has not shown a superior impact compared to other recovery techniques (Dupuy et al., 2018). Furthermore, the effect of the Blood Flow Restriction (BFR) technique on DOMS remains controversial in the scientific literature (Rodrigues et al., 2022). A combination of BFR and electrical stimulation has recently been studied and has shown no efficacy in preventing induced muscle damage (Cintron et al., 2024).

2.3 Passive recovery strategies

Compression treatment methods have shown a moderate effect on reducing DOMS and a lack of influence on muscle performance (Wisniowski et al., 2022). As for electrostimulation techniques, they remain controversial and studies have not revealed any clinically significant results in terms of reducing DOMS and recovering muscular capacity (Dupuy et al., 2018; Menezes et al., 2022). In addition, Whole-Body Cryotherapy (WBC) and partial-body cryotherapy have been recommended for the recovery of EIMD and have recently demonstrated similar responses on muscle performance, pain and markers of muscle damage (Azevedo et al., 2022). These cryotherapy strategies may be superior to passive recovery in improving DOMS but the authors did not find the best modality of application (Hohenauer et al., 2015). On the other hand, thermotherapy through the application of heat could be effective on DOMS but the duration required would be at least 8 hours continuously (Petrofsky et al., 2017). Finally, with regard to stretching, it is not always recommended after exertion and has not shown a significant positive effect in the treatment of DOMS (Dupuy et al., 2018).

2.4 Immersive recovery strategies

Among hydrotherapy methods, Cold Water Immersion (CWI) and Contrast Water Therapy (CWT) remain the most commonly described recovery techniques in the literature, despite their sometimes-controversial results. Indeed, some authors have found that CWI and CWT don’t improve recovery from perceived muscle soreness after team sports (Higgins et al., 2017). In contrast, other scientists mention the effectiveness of these methods in recovering from DOMS as well as their positive role in the athlete's performance and well-being (Ahokas et al., 2019; Dupuy et al., 2018). Furthermore, a survey on recovery strategies revealed that 88% of French professional football teams use CWT to improve team recovery (Nédelec et al., 2013). The effectiveness of this technique would be mainly related to hydrostatic pressure (reduction of oedema), analgesic phenomena (through local vasoconstriction during exposure to cold) as well as vasomotricity (combination of vasodilation and vasoconstriction), which would allow the movement of metabolic substances, repair of muscle damage and reduction of metabolic processes (Bieuzen, 2013). In addition, a systematic review reveals its significant effectiveness in reducing muscle strength loss compared to passive recovery (Bieuzen et al., 2013). Although there is a lack of consensus in the description of an optimal CWT protocol, specific guidelines have been proposed regarding water temperature, duration, and subject immersion level (Higgins et al., 2017; Versey et al., 2012; Versey et al., 2013). **Thus, the popularity and potential effectiveness of CWT in sports recovery explains the decision to integrate this technique into the project's conventional recovery protocol.**

2.5 Manual recovery strategy

Massotherapy is used by over 70% of French and Spanish football teams to help players recover (Altarriba-Bartes et al., 2021). Omnipresent in elite sport, the most common regime is a 30-60 minutes session for isolated treatment (Bezuglov et al., 2021), but a recent meta-analysis reveals that a 5-12 minutes massage appears to be sufficient to improve overall recovery (Poppendieck et al., 2016). Moreover, these scientists cite effleurage, kneading and deep gliding pressure as the manoeuvres most commonly used in sports. Despite a lack of consensus on an optimal application protocol, massage therapy has been identified as the most effective recovery technique for reducing DOMS and the perception of muscle fatigue. Indeed, manual pressure exerted on muscle tissue would improve neutrophil flushing of the affected area, preventing muscle fibre necrosis as well as the efflux of CK and IL-6 that circulate in the blood after exercise (Dupuy et al., 2018). On the other hand, biochemical changes, combining a reduction in cortisol with an increase in dopamine and serotonin, would explain a reduction in the feeling of pain (Nelson, 2013). However, there is no evidence that post-exercise sports massage is effective in improving performance (Davis et al., 2020). Nevertheless, athletes consider massage to be one of the most effective recovery methods (Bezuglov et al., 2021). **Thus, the popularity and potential effectiveness of massotherapy in sports recovery explains the decision to integrate this technique into the project's conventional recovery protocol.**

2.6 Whole-body Photobiomodulation Therapy (PBMT)

Definition: PBMT (or phototherapy) is light therapy that uses non-ionising light sources, such as lasers, Light-Emitting Diodes (LEDs) and broadband light, from the visible (380 to 780 nm) to the infrared (>780 nm) spectrum. It is a non-thermal, low-intensity process in which light interacts with chromophores, leading to photophysical and photochemical reactions in different tissues to relieve pain, reduce inflammation, modulate the immune response and promote tissue regeneration (Leal-Junior et al., 2019). To set up a PBMT protocol, a number of specific parameters need to be defined beforehand, including: wavelength (Nanometres), power (Watts), energy (Joules), irradiance (W/cm²), fluence (J/cm²), exposure time, irradiated surface area and application techniques, which may be local (face masks, pens…) or whole-body (panels, light beds…). An error in the settings could lead to a variation in the expected effects and incorrect targeting of the area to be treated (Annex C).

Principle of interaction: "Light-tissue" interactions can be classified into four different processes (Annex D): Absorption/diffusion and reflection/transmission (Mosca et al., 2019). These interactions are at the root of the clinical effectiveness of PBMT and are determined by the physical parameters of the light described above, as well as the tissue composition of the treated area. Indeed, the efficiency of light penetration into the skin is mainly related to the absorption spectra of three biological chromophores:

melanin in the epidermis, haemoglobin in the blood and water in the tissues. Therefore, if wavelength-specific chromophores are not present in the tissues, photons will pass through in total transmission without producing biological effects (Mosca et al., 2019). In addition, the physical energy of the light is progressively attenuated as it penetrates the tissue until it is completely extinguished. Thus, red and blue wavelengths (low penetration, high absorption) are preferred for treating superficial tissues, while infrared (low absorption, high penetration) targets deeper tissues. Researchers therefore describe red and infrared as the two popular PBMT wavelengths with physiological effects on human cells and tissues (Heiskanen & Hamblin, 2018). Finally, there is a “biphasic dose-response” model which describes an optimal value for the “dose” delivered by the device. For a given dosimetric value, an optimal response is achieved, but if the dose increases excessively, the physiological response decreases, and this could be the cause of negative or inhibitory effects. Thus, PBMT can have a stimulatory or inhibitory effect on the organism, depending on the physical parameters of the light (Hamblin, 2017). As a result, clinical guidelines for the use of PBMT have been described, particularly for improving physical performance and recovery after exercise (Leal-Junior et al., 2019).

Physiological mechanisms: Within the cell, there is strong evidence that PBM therapy acts on the mitochondria. Light is absorbed by chromophores, which are membrane proteins called Cytochrome c oxidase (COX) that function as photo acceptors. Absorption of the radiation then triggers a "biostimulation" characterised by various cellular mechanisms in the mitochondrial respiratory chain (Annex E): Membrane potential and Adenosine Triphosphate (ATP) production increase, Reactive Oxygen Species (ROS) are generated and Nitric Oxide (NO) is released by photodissociation between NO and COX (as a remember, NO is an inhibitor of cellular respiration that reduces ATP production). These cytosolic responses can activate transcription factors. These factors enable protein synthesis, which leads to significant cell proliferation, modulation of levels of cytokines, growth factors, inflammatory mediators and increased tissue oxygenation. This whole process acts as an exercise mimetic (Chung et al., 2012; Hamblin, 2018).

Evidence-based results: Among the key clinical results of PBMT, systemic reduction of inflammation is an important parameter in traumatic injuries, joint, lung and brain diseases (Hamblin, 2017). So far, the majority of research into muscle recovery has used devices targeting localised muscle groups, and the results obtained seem to be controversial. Indeed, several studies indicate no effectiveness of PBMT on DOMS and recovery of post-exertion performance (Azuma et al., 2021; D'Amico et al., 2022). Furthermore, a recent meta-analysis found no evidence that PBMT improves strength and functional capacity in healthy individuals (Bezerra et al., 2023). Finally, some researchers have found that PBMT is not superior to CWI (Malta et al., 2019). In view of these uncertainties, analysis of whole-body PBMT is relevant. A randomised crossover study suggests that its use would have a real benefit by treating more target tissues in less time (Ghigiarelli et al., 2020). However, the protocols vary, the number of studies is very small and not all scientists are agreed on the subject. Indeed, preliminary results on water polo athletes involving 5 minutes of whole-body PBMT, performed standing and using light panels, did not reveal a faster recovery of muscular inflammatory responses. Following these results, the scientists suggest that further research is needed to determine the ideal parameters for setting up a whole-body irradiation protocol (Zagatto et al., 2020). In addition, a whole-body PBMT protocol performed in a supine position with a light bed demonstrated an improvement in the post-exercise recovery of subjects after maximal anaerobic exercise (Wingate test), but did not reveal a positive effect on performance. The scientists concerned suggest a greater effect of these responses if the physical exercise involved the whole body and a higher level of requirement in terms of intensity and/or duration (Forsey et al., 2023). Whole-body PBMT has also shown convincing results on pain, stiffness, fatigue and quality of life in patients with fibromyalgia. These authors seem to consider this option as a promising treatment for chronic pain (Fitzmaurice et al, 2023). Finally, all these scientific studies highlight the scarcity of articles on the subject and describe a real need to study whole-body PBMT in order to understand the impact of this strategy on physiological recovery and its optimal application parameters. **Thus, the recent findings in the literature explain the decision to include this therapy in the project's experimental recovery protocol.**

METHODOLOGY

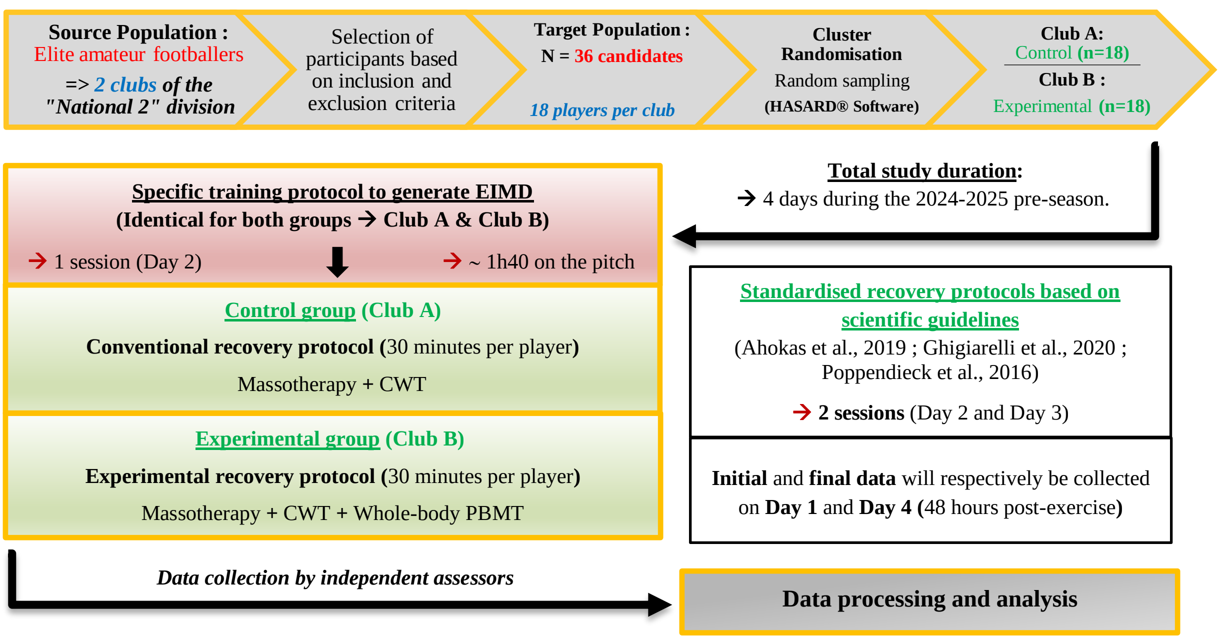
1. General and specific objectives of the study

The general objective of the study is to compare the effect of whole-body PBMT combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise recovery in elite amateur footballers affected by EIMD. The study has several specific objectives. The specific objectives are to compare the effects of whole-body PBMT combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise pain intensity, maximal muscle strength and power in elite amateur footballers affected by EIMD.

2. Study design and plan

The study is quantitative. It is a prospective experimental study conducted as a controlled clinical trial with parallel groups and cluster randomisation to limit bias and provide the highest level of scientific evidence.

Figure 1. Study design.



The study project is multicentric and will be set up in the two towns where the two French amateur football clubs selected for the experiment are located. This is the most realistic option for selecting the necessary number of subjects, taking into account the average number of players in a club (around 25) and anticipating on the participation criteria that could exclude some subjects. In this way, it will increase the statistical power of the study and allow faster recruitment of the population (reduction of time effect bias). The data will be assessed and processed in a blinded process by independent evaluators who are unaware of the group distribution in order to avoid acquisition bias.

3. Population and sample

3.1 Target population

The target population will be adult subjects belonging to the elite of amateur football and playing in the "National 2" championship. In fact, in a pyramidal vision of senior championships, this is the highest level in France, which is strictly non-professional (Appendice A). The choice of this elite population is explained by the desire to study players subjected to a heavy training load, in addition to the daily physical demands of their professional activities. The right balance between training load and post-exercise recovery is therefore necessary for these players predisposed to DOMS in order to avoid poor adaptation to the psychological and physiological stresses induced by exercise (Soligard et al., 2016).

3.2 Sample and sampling method

The sample will be determined from the target population and will be represented by two groups of equal proportion. The two amateur football clubs selected to participate in the study will make their teams available, from which the players to be included will be selected according to the participation criteria described later (Chapter 4). In the event that more players than required meet the criteria, the oldest players will be given priority for inclusion (see "Inclusion Criteria"). With regard to sampling, random clustering will be carried out using HASARD® software, which will enable an automatic drawing of lots. The selected clubs will then be listed, and the software will draw lots between these two clubs. The first club to be drawn will integrate the control group, while the second club will be part of the experimental group.

3.3 Sample size

In order to obtain a representative sample of the population, the number of subjects required was calculated using BiostatGV® software (Annex F), taking into account the Minimum Clinically Important Difference (MCID) set to ensure a clinically significant difference. This is a test comparing two means with two independent samples. The principal assessment criterion for the project is pain intensity in the lower limb, and the digital VAS will be used to evaluate this dependent variable. According to some authors, for the change in pain to be clinically significant, the study must show a decrease of 1.4 units on a VAS of 10 units, in other words a decrease of 14 mm on a total scale of 100 mm (Zheng-tao Lv et al., 2020). The standard deviation has been arbitrarily set at 1.4 units, equivalent to 14 mm, with a first-species risk $\alpha = 0.05$ and statistical power of 80% (Vedova, 2019). The type of test is bilateral. Thus, the resolution of the calculation reveals that the project requires a minimum of 32 players in order to have an 80% chance of obtaining a 14 mm difference between the groups. Finally, the number of subjects will be increased by 10% to take account of 'lost to view' participants, giving a total of 36 players to be included (18 players per club).

4. Characterisation and sample selection process

From the target population, the aim is to obtain a representative and homogeneous sample of the population, therefore only players meeting the participation criteria below will be included in the study (Table 1).

Table 1. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
→ **Voluntary amateur footballer**, licensed in a French club ("National 2" level), previously selected. → **Adult aged 30** (+/- 5 years). The oxidative system of a young subject is more efficient, so recovery is shorter (Cohen & Cantecorp, 2011). **The older subject is therefore a better model for this study project.** → Observe a strict **rest** period of at least **one week** before the start of the study. **A subject resuming physical activity is more likely to respond positively to the DOMS creation protocol.**	→ Players with **contraindications** to **CWT** and **Massotherapy** (diseases of the cardiovascular, respiratory and integumentary systems, Reynaud's syndrome, phlebitis, unhealed wounds, cold allergy, hydrophobia) and to **Whole-body PBMT**: cancer, psychiatric disorders, hypersensitivity to light, epilepsy, eye disorders and severe skin diseases (Fitzmaurice et al., 2022). → **History of recent lower limb trauma** (< 4 months) contraindicating heavy muscular exercise. **This could be the cause of poor tissue healing.** → **Subjects taking medication**, especially **anti-inflammatory** treatment. **This could be a source of pain bias** (Heiss et al., 2019). → **Occurrence of injury** during DOMS protocol creation (training protocol scheduled for Day 1). → Failure to comply with the terms of the study and use of **another recovery method** (Active recovery, cryotherapy…) → Unexpected **change of club** between seasons / **Voluntary withdrawal** from the project.

5. Evaluation criteria and data collection instruments

5.1 Evaluation criteria

The main evaluation criterion of the study will be the intensity of lower limb muscle pain, self-assessed using a digital Visual Analogue Scale (VAS). The secondary evaluation criteria will be the maximal muscular strength and power of the lower limbs measured by a "MyotestPRO®" accelerometer.

5.2 Data collection instruments

The Visual Analogue Scale (VAS) is a tool for the visual quantification of pain intensity. It is a simple, subjective and validated measurement instrument that allows self-assessment of pain sensation using a movable cursor on a millimetre scale ranging from 0 mm ("no pain") to 100 mm ("unbearable pain"), with a minimum clinically significant difference of 14 mm for muscular pain. (Zheng-tao Lv et al., 2020). To facilitate data collection, a digital VAS on a smartphone (« *EVA- Échelle Visuelle Analogiqu* » application) will be used as an assessment tool for lower limb muscle pain (Appendice B).

With regard to the "Myotest PRO®" instrument (Annex G), this is a measuring device equipped with a three-dimensional accelerometer to measure the acceleration of the load on a vertical axis in order to objectify certain criteria such as the speed, strength and muscular power generated during a sporting movement. It's a quick and easy measurement tool that requires no prior installation. Its compact size (the size of an MP3 player) and light weight (59 grams) mean that it can be carried and used directly on the pitch thanks to a waist belt (*L'appareil Myotest PRO*, 2014). The assessment of muscular performance will be determined by a vertical jump test (programmed into the control unit) to measure the maximal muscular strength and power generated during a “Countermovement Jump” (CMJ). Performed without the use of the upper limbs, the CMJ has the advantage of isolating the action of the lower limbs from the action of the arms; the latter being able to influence the performance of the jump. Moreover, it involves the "stretching-shortening" cycle of the muscles (plyometric effect), which makes it more representative of the movements performed during football practice.

Table 2. Validity and reliability of measurement instruments.

Digital **Visual Analogue Scale (VAS)**	Accelerometer **« MyotestPRO® »**
→ This is a **validated measurement instrument** (Zheng-tao Lv et al., 2020) commonly used to assess pain intensity, and whose evidence supports its **reliability** and **validity** in various populations (Ferreira-Valente et al., 2011). Some authors have demonstrated that the digital version (on smartphone or laptop) shows no clinically relevant difference (Delgado et al., 2018).	→ The “MyotestPRO®” measuring device provides **precise** and **reproducible values** whose **validity** and **reliability** have been demonstrated by various authors (Castagna et al., 2012; Choukou et al., 2014). Studies indicate that the parameters measured by these pre-programmed tests are **reliable**.

6. Variables

The independent variable of the study will be the type of recovery performed according to the allocation group (Table 3). The dependent variables correspond to the judging criteria and will be assessed in a blinded process by independent assessors who will be unaware of the groups' distribution. The main assessment criterion will be the intensity of muscle pain in the lower limb. This is an important clinical feature since delayed muscle soreness is the most common clinical manifestation following high-volume plyometric training in professional and amateur athletes (Cheung et al., 2013).

The secondary evaluation criteria will be the maximal muscular strength and power of the lower limb. These functional parameters, which are affected by DOMS, are essential for the achievement of sports performance associated with football. Therefore, it seems appropriate to assess these two components in the target population.

Table 3. Independent variable and dependent variables

Group (N=36)	Independent variable	Dependent variables
CRTL Group (n=18)	Conventional recovery protocol	→ Pain intensity in the lower limbs (DOMS) → Maximal muscular strength and power of the lower limbs.
EXP Group (n=18)	Whole-body PBM Therapy + Conventional recovery protocol	

7. Hypotheses of the study

The study project is based on two types of hypotheses, which are summarised in the form of a table: (Appendice C)

The null hypothesis (H0): The experimental recovery protocol shows no clinically significant difference from the conventional recovery protocol on post-exertion pain intensity, maximal muscle strength and power of the lower limbs in amateur footballers affected by EIMD.

Alternative hypotheses (H1): The experimental recovery protocol shows a clinically significant difference compared with the conventional recovery protocol on post-exertion pain intensity and/or maximal muscle strength and/or power of the lower limbs in amateur footballers affected by EIMD.

8. Application procedures with references to authorisation requests

8.1 Choice of partners, human resources and techniques

Initially, a partnership will be sought with two football clubs playing in the "National 2" Championship for the 2024-2025 season. Therefore, with the exception of the "reserve teams" of the professional clubs (second team of the professional clubs) that can play in this league, all the "National 2" teams (Annex H) will be contacted by means of an e-mail intended for the clubs' managers and the referring doctor, in order to send a poster promoting of the study (Appendice D), to announce the objectives of the project as well as the participation criteria for the subjects. It would be judicious to contact the French Football Federation (FFF), which is the institution responsible for this championship (Appendice E), in order to obtain the contact details of these clubs and/or to promote the project. As the study is multicentric and carried out in a single-blind process, it will require three principal investigator physiotherapists in each of the selected cities to be in charge of the different protocols (EIMD creation protocol / Recovery protocols) and one evaluator physiotherapist responsible for data collection. The main characteristic allowing to designate the principal investigators will be to be sports specialists in order to have a good knowledge of the recovery techniques used, as well as muscular pains related to sports practice. For the physiotherapist assessors, a good knowledge of biostatistics and of the selected assessment instruments will be required. A prior training session on the techniques used and the assessment tools will be held before the study in order to standardise the interventions. Professionals practising not far from the study sites will be canvassed by email or via social networks (LinkedIn®, Instagram®, Facebook®) to be invited to take part in the project. The message sent will specify the profile sought, the objectives of the study and the implementation modalities. Furthermore, to carry out the study, a partnership request (Appendice F) will be established with several wellness centres and rental companies specialised in sports and medical equipment, with a view to collecting all the material required for the study (Appendice G). Thus, each club will be equipped with: massage tables, a neutral massage cream, a cold water bath and a hot water bath. For the club subject to the experimental recovery protocol, the Whole-body PBMT system selected for the experiment will be added. Developed by BioLedTherapy® (a French company specialised in this field), the device will be recruited by contacting the manufacturer's partner companies that may have the required equipment (Appendice E). This process will avoid any potential conflict of interest with the manufacturer. The email sent will describe the terms of the study, the purpose of the request and will include the promotional poster provided for this purpose (Appendice F). As regards the assessment tools, the same procedure will be performed by contacting the manufacturer of the MyotestPRO® measuring device (Appendices E & F). Finally, the digital application "*EVA- Échelle Visuelle Analogiqu*" can be installed (in an identical version) directly on the smartphones of the assessors' physiotherapists.

8.2 Sample selection and groups constitution

After the partnership research, it will be necessary to select the sample to form the groups. As a reminder, when the club receives the informative e-mail, the referring doctor will also have received the participation criteria, allowing him (or her) to present the study to the players and determine the potential involvement of the club in the project. Thus, if more than two clubs respond positively to the request, preference will be given to those with the highest weekly training load, reinforcing the general idea of the study targeting the elite of amateur football. If less than two clubs are interested in the project, lower league clubs ("National 3") will be included. Once the partnerships have been established, the two clubs will be informed as soon as possible of the results of the random cluster sampling (see Chapter 3.2), which will determine the recovery protocol to which they will be subjected (control or experimental group). Subjects will be selected from the target population according to the inclusion and exclusion criteria. Each of the volunteers selected for the study will be contacted quickly by telephone and will receive an e-mail containing the free and informed consent form (Fernandez & Catteuw, 2001), which must be signed before the start of the experiment (Appendice H). Finally, to facilitate data collection and manipulation, the HASARD® software will also allow each participant to be assigned a number from 1 to 36 according to their group (1-18 for the control group / 19 to 36 for the experimental group).

8.3 Intervention protocol

Each of the two selected clubs will have to make its players and facilities available for the entire duration of the project, that is, for the first four days of the 2024-2025 pre-season (Table 4). In addition, the players will have to respect, as far as possible and for the entire duration of the experiment, the following conditions: relative rest during the day, strict hydration with 2 litres of water per day and, if possible, a full night's sleep (ideally 8 hours per night). These parameters can influence the athlete's recovery (Palsson et al., 2023; Thomas et al., 2016) so they are standardised.

Table 4. Chronology of the experiment.

Time \ Day	**Day 1** *Saturday*	**Day 2** *Sunday*	**Day 3** *Monday*	**Day 4** *Tuesday*
4 pm – 6 pm		**EIMD creation protocol**		
From 6 pm	**Initial data collection**	**Recovery Protocol** (Session 1)	**Recovery Protocol** (Session 2)	**Final data collection**

Note: *The final data collection will take place on Day 4 from 6pm,* ***exactly 48 hours after the end of the training protocol****. Indeed, some authors suggest that the peak of DOMS occurs 48 hours after exercise (Nelson, 2013)*

8.3.1 EIMD generator training procedure

An intensive training protocol with the aim to create EIMD will be set up identically in the two selected football clubs. To this end, the three principal investigators assigned to a club may be accompanied by the club's physical preparer in order to rigorously supervise the training. The protocol will be carried out in 4 successive steps (entirely on the pitch, ≈ 1h40), alternating exercises with and without the ball. It will begin with a full warm-up **(Step 1)**, whose effectiveness has been scientifically proven. The "11+" warm-up protocol (Annex I), created by FIFA, was developed by international football and health experts (Bizzini & Dvorak, 2015). The training will continue by a physical exercise with the ball called "*Circuit passe et suit*" **(Step 2).** This is a technical exercise allowing the players to work physically and playfully thanks to the utilisation of the ball. The session will follow by a physical exercise without ball **(Step 3)**, which will combine a lower limb muscle-strengthening phase and a running workout with change of supports. Finally, the protocol will end by a match with themes to encourage the physical strain of all the players **(Step 4).** Indeed, the physical demands that it requires (duels, pass, acceleration/deceleration, sprints, changes of supports…) justify its relevance. The detail of this training protocol standardises the intervention (Appendices I & J). At the end of the intensive training session, the players will go to the club's premises to begin the recovery protocol. For hygienic reasons, a short shower at room temperature will be taken before the start of the protocol. The three principal investigators assigned to a club will take charge of the recovery protocol following the intensive training protocol.

8.3.2 Conventional recovery protocol procedure

The conventional recovery protocol for the **control group** (Club A) will be carried out in two parts, for a total duration of **30 minutes** per player. The **first part** will consist of a therapeutic massage of the lower limbs on the muscles frequently affected by DOMS (Quadriceps, Hamstrings, Triceps surae) (Coudreuse et al., 2004). The investigators will use the manoeuvres most commonly described in sports practice, in particular effleurage, deep gliding pressure and kneading (Poppendieck et al., 2016) for a total duration of 15 minutes. Studies differ on this subject and there is no consensus on the duration of massage in sports practice. In fact, some authors have observed long application times (30 to 60 minutes) for a single sports massage (Bezuglov et al., 2021), while other authors recommend short massages of less than 15 minutes (Poppendieck et al., 2016). Finally, the manoeuvres performed should be relatively slow, tolerated by the player and carried out centripetally, following the vascular pathway of the venous return. The **second part** of the protocol will continue with immersion therapy. For the implementation of CWT, the investigators will follow the recommendations described by Higgins et al. (2017): The total duration of immersion will be exactly 15 minutes, divided into 5 consecutive immersions (Hot water / cold water) of 3 minutes each. In addition, temperatures will be fixed at 10°C for the cold water bath and 38°C for the hot water bath. Finally, the immersed player will have to maintain an optimal immersion position as described by the investigators. Thus, the entire conventional recovery protocol will be standardised on the basis of scientific data. A summary of this conventional protocol is presented in tabular form (Appendice K).

8.3.3 Experimental recovery protocol procedure

The recovery protocol for the **experimental group** (Club B) will be divided into three parts for a total duration of **30 minutes** per player. The **first part** will consist of a therapeutic massage which will follow the same procedures as the conventional group in terms of the material used, the position of the subject and the chronology of the manoeuvres performed. Nonetheless, the total duration of the massage will follow the recommendations of Poppendieck et al. (2016) and will be set at 9 minutes. The **second part** of the protocol will continue with the CWT, which will be applied according to the same parameters as the conventional group in terms of the equipment used, the temperature of the baths and the position of the subject in immersion. However, the total duration of the immersion will be set at 6 minutes (Versey et al., 2012). Finally, the **third part** of the protocol will involve Whole-body PBMT for a total of 15 minutes. After immersion, the subject will be allowed to dry off and settle under the Whole-body PBMT device following the investigator's instructions. Beforehand, the light irradiation will be precisely configured according to the clinical guidelines described by Leal-Junior et al. (2019) for use in sports. Indeed, the authors suggest an optimal dose of between 30 and 60 J for small muscle groups (Triceps Surae) and between 60 and 300 J for more voluminous muscles (Quadriceps, Hamstrings). Therefore, the configuration of the device will be calculated to ensure that the irradiation dose to the main muscle groups of the lower limb (Quadriceps, Hamstring, Triceps Surae) follows the recommended values. Knowing that the ineffectiveness of a treatment on cells with high mitochondrial activity (muscles, brain, heart, nerves) is more often due to overdosing than underdosing (Zein et al. 2018). Thus, the entire experimental recovery protocol will be standardised on the basis of scientific data. A summary of this protocol is presented in tabular form with precision on device configuration (Appendices L & M).

8.4 Assessment protocol

Within the clubs, independent physiotherapists will carry out single-blind evaluation of the different assessment criteria on the first day and the last day of the study, starting from 6 pm. In order to avoid any potential alteration in pain perception, caused by an assessment of muscular performance carried out in the first instance, data collection will begin with an assessment of the intensity of muscular pain in the lower limbs, using a digital VAS. Indeed, the subject will be asked to self-assess the pain intensity on a touch screen (Appendice B), by moving the mobile cursor along a horizontal line bounded by a left end ("No pain") and a right end ("Maximum imaginable pain"). Muscle strength and power will be assessed using the "MyotestPRO®" measuring device, which will analyse the data generated during a vertical jump (CMJ). Thus, the assessor physiotherapist will be in charge of setting up the device by entering the user's details into the control box (Name, Height, Weight, Age) and selecting the desired program (CMJ). The assessor will also ensure that the device is correctly installed on the participant and will give the necessary instructions for the correct execution of the test (Annex J). A summary of this evaluation protocol is presented in tabular form (Appendix N)

9. Data processing plan

Following the various assessments, the data collected will be listed and classified in an Excel® table. Means, variances and standard deviations will be calculated for each sample. In order to determine which statistical test should be used for this study, the normality of the distribution must be verified using the Sharipo-Wilk test. If the sample follows a normal (Gaussian) distribution, it will be possible to generalise to a population (Royston, 1982). Furthermore, it is essential to use the parametric test according to the characteristics of the project. The study consists of two unpaired groups whose protocol provides for the collection of data at two well-defined times T (before and after the recovery protocol). Thus, the statistical analysis adapted for this experiment is the ANalysis Of VAriance (ANOVA) with repeated measures to check that the distribution of the groups is comparable and to eliminate inter-individual variability (McHugh, 2011). Post-hoc analysis using the Tukey test is used to calculate the p-value for each group in order to determine whether or not the difference between the groups is significant (McHugh, 2011). The risk of error α being set at 5%: if the p-value > 5% then the null hypothesis will be accepted and the alternative hypotheses will be rejected. Conversely, if the p-value < 5%, we will accept one of the alternative hypotheses and will reject the null hypothesis. Finally, the data collected will be presented in the form of a histogram to provide the reader with an intelligible transcription of the results.

CRITICAL REFLECTIONS AND CONCLUSION

The purpose of this chapter is to provide a critical reflection on the implementation of the study project. The scientific literature cited in this section has already been mentioned and does not provide the reader with any additional information.

Firstly, the analysis of the literature developed in the "Introduction" and in the "Theoretical framework" proves that sports recovery is a subject widely studied by scientists and which reveals numerous therapeutic options (Nédelec et al., 2013). However, the lack of evidence regarding the effectiveness of certain techniques (Dupuy et al., 2018), the large variety of existing protocols (Bezuglov et al., 2021), as well as the controversial results on the emergence of recent therapeutic methods that are poorly described in the literature (Forsey et al., 2023; Ghigiarelli et al., 2020), justify the potential difficulty for therapists to position themselves on an effective recovery strategy. On the basis of these data, the choice of a study focusing on whole-body PBMT seemed coherent in view of the limitations raised by the current scientific literature. As a reminder, despite the sometimes mixed results (Forsey et al., 2023; Zagatto et al., 2020), the therapeutic action of PBM could have a greater effect on post-exercise recovery when it involves the whole-body (Ghigiarelli et al., 2020). In quantitative terms, scientists are unanimous. They point out that there are too few studies on whole-body PBMT and suggest that more research is needed to understand its impact on the athlete's physiological recovery. Therefore, the study project responds to the need of the current scientific literature and contributes to the democratisation of whole-body PBMT in terms of post-exercise recovery.

To this end, the prospective experimental study will be quantitative, controlled and randomised to test pre-formulated hypotheses with the highest level of scientific evidence. Cluster randomisation will reduce logistical requirements, facilitate coordination of protocols and, above all, obtain a representative sample of the population to avoid selection bias. Comparison with a control group will limit confusion bias. In addition, the clinical trial will be multicentric and set up in the two French football clubs selected for the experiment. This option is the most realistic to allow a sufficient selection of the necessary number of subjects, taking into account the average number of players in a club (around 25 players) and anticipating on the participation criteria that could exclude some subjects. In addition, it will increase the statistical power of the study and allow the population to be recruited more quickly (reduction in time-effect bias). Finally, the involvement of several centres will give a better representation of current clinical practice, which could improve the external validity of the results. With regard to the assessment of the various evaluation criteria, this will be carried out in a blinded process by independent assessors who will be unaware of the groups' distribution. This approach has the advantage of making the evaluator impartial in order to avoid data acquisition bias.

However, the multicentric nature and the blind evaluation could also be a source of bias: the study will take place in two different cities, which will require three principal investigators (to facilitate protocols management) and one assessor physiotherapist in each of the selected cities. In this way, the intervention protocols could differ from one club to another according to the practitioners present on site, which could represent a study bias linked to inter-individual variability. Nevertheless, this risk seems to be negligible in view of the precautions taken in this respect (described later). Furthermore, in order to facilitate the logistics and the design of the study, a third group (placebo group) will not be added to the project, which could represent a confusion bias. If the experimental protocol proves to be effective, it would be appropriate for subsequent studies to verify this parameter in order to avoid the potential placebo effect.

As regards the population studied, the overall number of subjects required is relatively small, and therefore the study will have low statistical power. Nevertheless, the calculation takes into account the MCID of the main assessment criterion in order to obtain reliable and clinically significant results. The multicentric nature of the study should make it easy to obtain the necessary number of subjects. If less than two clubs are interested by the project, it will be necessary to adapt by including lower level clubs. In addition, to avoid a bias in the selection of 'lost players', it has been planned to increase the number of subjects required by 10%, giving a total of 36 players to include in the project. Subjects will initially be selected on the basis of participation criteria.

The control of these different criteria (inclusion/exclusion) will avoid the appearance of recruitment bias.

Regarding the intervention protocol, it will begin with a common intensive training session, standardised with a playful and reproducible conception by all the football clubs. Moreover, it will be built according to a progressive physical intensity by including a warm-up program ("11+") scientifically validated by the highest authority of world football (FIFA). The study will continue with the implementation of the respective recovery protocols (Control / Experimental). Standardised, reproducible and following scientific guidelines, the investigators will be able to follow a precise and detailed description of these protocols in order to limit follow-up bias. In addition, as the treatment time is identical for the control and experimental groups (30 minutes per player), the study will be free from dose-effect bias. With regard to the evaluation protocol, the exact time of final data collection will be carried out in accordance with scientific data (48 hours after training), by an evaluator who differs from one club to another, but using identical collection instruments.

Thus, with a view to improve the recovery of amateur players thanks to an accessible protocol for as many clubs as possible, the choice of equipment and assessment tools was made according to some characteristics: **Reliability, Reproducibility, Accessibility**, **Simplified Implementation**. Indeed, as the equipment needed to carry out the massotherapy and CWT protocols is relatively basic, it seems unlikely that companies will not be able to supply this kind of equipment. Similarly for the Whole-body PBMT device (BioLedTherapy® light panels); Its transportable, removable and relatively inexpensive properties (compared with a Whole-body PBMT cabin) give it a better representation in terms of reproducibility for routine practice. This ease of access will enable the set-up of 4 units of this type in order to optimise the protocol management and carry out the different steps of the experimental treatment without interruption, thus standardising the protocol for all players. The choice of this equipment ensures the reliability of the treatment and reinforces the external consistency of the study.

The same consideration was applied to the choice of assessment tools. The digital VAS will provide a simple and reliable measurement with rapid acquisition of values (Delgado et al., 2018). However, the subjective nature of the assessment depends on the subjects' relationship with their pain, which could cause difficulties in the reproducibility of the studies. With regard to the MyotestPRO® measuring device, it has the advantage of being scientifically reliable (Castagna et al., 2012; Choukou et al., 2014) and its implementation is simplified since measurements can be made directly in the field. This option seems to be suitable for the study project targeting a population of amateur players. In fact, another technique exists, such as the isokinetic dynamometer, which is more accurate in terms of measurement, but would be less simple to set up. Its use would not be consistent with the concept of the study (high cost, limited accessibility, reduced ease of acquisition, etc.). Finally, if the MyotestPRO® is not available, another reliable assessment tool of the same calibre, such as the "force platform", could be used to collect data.

Thus, the standardisation of the intervention protocols, the appointment of investigators from outside the structure, and the prior training on the equipment and data collection tools (identical for both groups) will make it possible to limit the centre-effect bias while increasing the internal validity of the study. However, despite the planning designed to limit unavailability (weekends, late hours) as well as the standardisation of sleep, hydration and rest outside the study to reduce bias linked to the subjects' environment, certain factors related to the participants' profession will not be controllable. As a reminder, the majority of amateur players have a professional activity outside football, which is more or less intense and time-consuming according to their job. This variability between subjects could constitute a confusion bias.

Following data processing, the analysis of the results will be used to validate the null hypothesis (H0) or the alternative hypothesis (H1).

If the null hypothesis (H0) is validated, it will be concluded that the experimental recovery protocol does not show a significant difference compared to the conventional recovery protocol on post-exertion pain intensity, maximal muscle strength and power of the lower limb in amateur footballers affected by EIMD. The validation of this hypothesis would be in line with a randomised crossover study showing a lack of significant results from whole-body PBMT in the reduction of certain inflammatory markers (Ghigiarelli et al., 2020). In this case, it is possible that the EIMD creation protocol is not sufficiently effective in its function and causes a lack of significance of the recovery protocol on the parameters studied. Furthermore, it is possible that the frequency of application is insufficient and requires an increase in the number of sessions. Finally, it is possible that the irradiation dose for whole-body PBM therapy is not optimal and does not allow effective biostimulation. If these options were to be confirmed, the study project would have to be continued by modifying certain parameters (increase in the intensity of the training protocol, in the frequency of the therapeutic sessions and/or in the the dose of light irradiation).

If the alternative hypothesis (H1) is validated, it will be concluded that the experimental recovery protocol shows a significant difference compared to the conventional recovery protocol on post-exertion pain intensity and/or maximal muscle strength and/or power of the lower limb in amateur footballers affected by EIMD. In the case of a significant decrease in the results, the "biphasic dose-response" model (characteristic of PBMT) could be the cause of the negative or inhibitory effects on the post-exertional recovery of the variables measured. It would be appropriate to readjust the protocol by reducing the dose of light irradiation in order to obtain optimal biostimulation. Conversely, in the event of an improvement in the measured parameters, this experimental therapy could be considered as an Evidence Based Practise (EPB) recovery strategy and would demonstrate the relevant results of whole-body PBMT in this field, providing a positive response to scientists (Forsey et al., 2023; Ghigiarelli et al., 2020; Zagatto et al., 2020). In addition, these results would respond to a recent meta-analysis (Dupuy et al., 2018) that questions the potential synergistic effects of a protocol combining several recovery techniques. It would then be interesting to study this protocol on other key performance factors (endurance, speed, fatigue) specific to football, but also in other different sports or in populations of professional athletes.

Finally, all the Annexes / Appendices presented in this work have been written in English to facilitate the understanding of the reviewer. However, as the study is aimed at a French population, it will be planned to send a French version of these documents to the organisations and subjects involved in the study.

In conclusion, the study project contributes to the democratisation of whole-body PBMT and would enable to determine the significant interest of its use in the post-exertional recovery of 'elite' amateur footballers. If the statistical analysis of the results proves the effectiveness of this experimental protocol, the study project would facilitate the decision of amateur clubs to invest in this type of equipment and would provide a complementary therapeutic option for sports physiotherapists. In fact, the simplicity of implementation, its accessibility and its reproducibility are advantages that would allow a large number of clubs (even the most modest) to incorporate this efficient recovery protocol, based on the **Evidence Based Practice** **(EBP)** model, into a team's post-exercise routine. In order to broaden the study's scope towards new perspectives, it would be relevant to compare the results obtained with an experiment carried out on a different sporting population, in which the muscular load would be more concentrated on the upper limb. In addition, a prospective study conducted over a complete season (at minimum) would also be interesting and would allow to analyse the potential prophylactic effects of this experimental protocol on the prevention of other muscular pathologies such as myoaponeurotic damage, or the onset of tendinopathy.

BIBLIOGRAPHIC REFERENCES

Ahokas, E. K., Ihalainen, J. K., Kyröläinen, H., & Mero, A. A. (2019). Effects of Water Immersion Methods on Postexercise Recovery of Physical and Mental Performance. *Journal of Strength and Conditioning Research*, *33*(6), 1488-1495. https://doi.org/10.1519/JSC.0000000000003134

Altarriba-Bartes, A., Peña, J., Vicens-Bordas, J., Casals, M., Peirau, X., & Calleja-González, J. (2021). The use of recovery strategies by Spanish first division soccer teams: A cross-sectional survey. *The Physician and Sportsmedicine*, *49*(3), 297-307. https://doi.org/10.1080/00913847.2020.1819150

Azevedo, K. P., Bastos, J. A. I., de Sousa Neto, I. V., Pastre, C. M., & Durigan, J. L. Q. (2022). Different Cryotherapy Modalities Demonstrate Similar Effects on Muscle Performance, Soreness, and Damage in Healthy Individuals and Athletes: A Systematic Review with Metanalysis. *Journal of Clinical Medicine*, *11*(15), 4441. https://doi.org/10.3390/jcm11154441

Azuma, R. H. E., Merlo, J. K., Jacinto, J. L., Borim, J. M., da Silva, R. A., Pacagnelli, F. L., Nunes, J. P., Ribeiro, A. S., & Aguiar, A. F. (2021). Photobiomodulation Therapy at 808 nm Does Not Improve Biceps Brachii Performance to Exhaustion and Delayed-Onset Muscle Soreness in Young Adult Women : A Randomized, Controlled, Crossover Trial. *Frontiers in Physiology*, *12*, 664582. https://doi.org/10.3389/fphys.2021.664582

Bezerra, L. O., de Macedo, L. E. S., da Silva, M. L. A., de Oliveira, J. M. P., de Morais Gouveia, G. P., de Andrade, P. R., & Micussi, M. T. A. B. C. (2023). Effects of photobiomodulation therapy on the functional performance of healthy individuals: A systematic review with meta-analysis. *Lasers in Medical Science*, *39*(1), 17. https://doi.org/10.1007/s10103-023-03956-2

Bezuglov, E., Lazarev, A., Khaitin, V., Chegin, S., Tikhonova, A., Talibov, O., Gerasimuk, D., & Waśkiewicz, Z. (2021). The Prevalence of Use of Various Post-Exercise Recovery Methods after Training among Elite Endurance Athletes. *International Journal of Environmental Research and Public Health*, *18*(21), 11698. https://doi.org/10.3390/ijerph182111698

Bieuzen, F. (2013). Chapitre 16. La récupération par immersion. In C. Hausswirth (Éd.), *Améliorer sa récupération en sport* (p. 281-293). INSEP-Éditions. http://books.openedition.org/insep/1378

Bieuzen, F., Bleakley, C. M., & Costello, J. T. (2013). Contrast Water Therapy and Exercise Induced Muscle Damage : A Systematic Review and Meta-Analysis. *PLoS ONE, 8*(4). https://doi.org/10.1371/journal.pone.0062356

Bizzini, M., & Dvorak, J. (2015). FIFA 11+ : An effective programme to prevent football injuries in various player groups worldwide-a narrative review. *British Journal of Sports Medicine*, *49*(9), 577-579. https://doi.org/10.1136/bjsports-2015-094765

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage : Theoretical and applied implications. *Sports Medicine (Auckland, N.Z.)*, *34*(1), 49-69. https://doi.org/10.2165/00007256-200434010-00005

Castagna, C., Ganzetti, M., Ditroilo, M., Giovannelli, M., Rocchetti, A., & Manzi, V. (2012). Concurrent Validity of Vertical Jump Performance Assessment Systems. *Journal of strength and conditioning research / National Strength & Conditioning Association*, *27*. https://doi.org/10.1519/JSC.0b013e31825dbcc5

Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed Onset Muscle Soreness. *Sports Medicine*, *33*(2), 145-164. https://doi.org/10.2165/00007256-200333020-00005

Choukou, M.-A., Laffaye, G., & Taiar, R. (2014). Reliabiity And Validity Of An Accelerometric System For Assessing Vertical Jumping Performance. *Biology of Sport*, *31*(1), 55-62. https://doi.org/10.5604/20831862.1086733

Chung, H., Dai, T., Sharma, S. K., Huang, Y.-Y., Carroll, J. D., & Hamblin, M. R. (2012). The Nuts and Bolts of Low-level Laser (Light) Therapy. *Annals of Biomedical Engineering*, *40*(2), 516-533. https://doi.org/10.1007/s10439-011-0454-7

Cintron, H. E., Heyburn, J. J., Sterner, R. L., & Dankel, S. J. (2024). Blood Flow Restricted Electrical Stimulations to Prevent or Attenuate Symptoms of Muscle

Damage. *Research in Sports Medicine (Print)*, *32*(1), 213-224. https://doi.org/10.1080/15438627.2022.2132862

Cochrane, D. J. (2004). Alternating hot and cold water immersion for athlete recovery : A review. *Physical Therapy in Sport*, *5*(1), 26-32. https://doi.org/10.1016/j.ptsp.2003.10.002

Cohen, J., & Cantecorp, K. (2011). Les DOMS : Compréhension d'un mécanisme en vue d'un traitement masso-kinésithérapique préventif. https://www.em-consulte.com/en/article/297291

Coudreuse, J. M., Dupont, P., & Nicol, C. (2004). Douleurs musculaires posteffort. *Annales de Réadaptation et de Médecine Physique*, *47*(6), 290-298. https://doi.org/10.1016/j.annrmp.2004.05.012

Coudreuse, J.-M., Dupont, P., & Nicol, C. (2007). Douleurs musculaires post-effort. *Journal de Traumatologie du Sport*, *24*(2), 103-110. https://doi.org/10.1016/j.jts.2007.03.006

D'Amico, A., Silva, K., Rubero, A., Dion, S., Gillis, J., & Gallo, J. (2022). The Influence of Phototherapy on Recovery From Exercise-Induced Muscle Damage. *International Journal of Sports Physical Therapy*, *17*(4), 658-668. https://doi.org/10.26603/001c.34422

Davis, H. L., Alabed, S., & Chico, T. J. A. (2020). Effect of sports massage on performance and recovery: A systematic review and meta-analysis. *BMJ Open Sport & Exercise Medicine*, *6*(1). https://doi.org/10.1136/bmjsem-2019-000614

Delgado, D., Lambert, B., Boutris, N., McCullock, P., Robbins, A., Moreno, M., & Harris, J. (2018). Validation of Digital Visual Analog Scale Pain Scoring With a Traditional Paper-based Visual Analog Scale in Adults. *Journal of the American Academy of Orthopaedic Surgeons. Global Research & Reviews*, *2*(3), e088-e088. https://doi.org/10.5435/jaaosglobal-d-17-00088

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An Evidence-Based Approach for Choosing Post-exercise Recovery Techniques to Reduce Markers of Muscle Damage, Soreness, Fatigue, and Inflammation: A Systematic Review With Meta-Analysis. *Frontiers in Physiology*, *9*. https://doi.org/10.3389/fphys.2018.00403

Ferreira-Valente, M. A., Pais-Ribeiro, J. L., & Jensen, M. P. (2011). Validity of four pain intensity rating scales. *Pain*, *152*(10), 2399-2404. https://doi.org/10.1016/j.pain.2011.07.005

Fitzmaurice, B. C., Heneghan, N. R., Rayen, A. T. A., Grenfell, R. L., & Soundy, A. A. (2023). Whole-Body Photobiomodulation Therapy for Fibromyalgia : A Feasibility Trial. *Behavioral Sciences (Basel, Switzerland)*, *13*(9), 717. https://doi.org/10.3390/bs13090717

Fitzmaurice, B., Heneghan, N. R., Rayen, A., & Soundy, A. (2022). Whole-body photobiomodulation therapy for chronic pain : A protocol for a feasibility trial. *BMJ Open*, *12*(6), e060058. https://doi.org/10.1136/bmjopen-2021-060058

Forsey, J. D., Merrigan, J. J., Stone, J. D., Stephenson, M. D., Ramadan, J., Galster, S. M., Bryner, R. W., & Hagen, J. A. (2023). Whole-body photobiomodulation improves post-exercise recovery but does not affect performance or physiological response during maximal anaerobic cycling. *Lasers in Medical Science*, *38*(1), 111. https://doi.org/10.1007/s10103-023-03759-5

Ghigiarelli, J. J., Fulop, A. M., Burke, A. A., Ferrara, A. J., Sell, K. M., Gonzalez, A. M., Pelton, L. M., Zimmerman, J. A., Coke, S. G., & Marshall, D. G. (2020). The Effects of Whole-Body Photobiomodulation Light-Bed Therapy on Creatine Kinase and Salivary Interleukin-6 in a Sample of Trained Males : A Randomized, Crossover Study. *Frontiers in Sports and Active Living*, *2*. https://www.frontiersin.org/articles/10.3389/fspor.2020.00048

Hägglund, M., Waldén, M., & Ekstrand, J. (2013). Risk factors for lower extremity muscle injury in professional soccer: The UEFA Injury Study. *The American Journal of Sports Medicine*, *41*(2), 327-335. https://doi.org/10.1177/0363546512470634

Hamblin, M. R. (2017). Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. *AIMS biophysics*, *4*(3), 337-361. https://doi.org/10.3934/biophy.2017.3.337

Hamblin, M. R. (2018). Mechanisms and Mitochondrial Redox Signaling in Photobiomodulation. *Photochemistry and photobiology*, *94*(2), 199-212. https://doi.org/10.1111/php.12864

Heiskanen, V., & Hamblin, M. R. (2018). Photobiomodulation : Lasers vs. light emitting diodes? *Photochemical & Photobiological Sciences*, *17*(8), 1003-1017. https://doi.org/10.1039/C8PP00176F

Heiss, R., Lutter, C., Freiwald, J., Hoppe, M. W., Grim, C., Poettgen, K., Forst, R., Bloch, W., Hüttel, M., & Hotfiel, T. (2019). Advances in Delayed-Onset Muscle Soreness (DOMS) - Part II : Treatment and Prevention. *Sportverletzung Sportschaden: Organ Der Gesellschaft Fur Orthopadisch-Traumatologische Sportmedizin*, *33*(1), 21-29. https://doi.org/10.1055/a-0810-3516

Higgins, T. R., Greene, D. A., & Baker, M. K. (2017). Effects of Cold Water Immersion and Contrast Water Therapy for Recovery From Team Sport : A Systematic Review and Meta-analysis. *The Journal of Strength & Conditioning Research*, *31*(5), 1443. https://doi.org/10.1519/JSC.0000000000001559

Hohenauer, E., Taeymans, J., Baeyens, J.-P., Clarys, P., & Clijsen, R. (2015). The Effect of Post-Exercise Cryotherapy on Recovery Characteristics : A Systematic Review and Meta-Analysis. *PloS One*, *10*(9), e0139028. https://doi.org/10.1371/journal.pone.0139028

Hotfiel, T., Freiwald, J., Hoppe, M. W., Lutter, C., Forst, R., Grim, C., Bloch, W., Hüttel, M., & Heiss, R. (2018). Advances in Delayed-Onset Muscle Soreness (DOMS) : Part I: Pathogenesis and Diagnostics. *Sportverletzung Sportschaden: Organ Der Gesellschaft Fur Orthopadisch-Traumatologische Sportmedizin*, *32*(4), 243-250. https://doi.org/10.1055/a-0753-1884

Jones, A., Jones, G., Greig, N., Bower, P., Brown, J., Hind, K., & Francis, P. (2019). Epidemiology of injury in English Professional Football players : A cohort study. *Physical Therapy in Sport*, *35*, 18-22. https://doi.org/10.1016/j.ptsp.2018.10.011

Kim, J., & Lee, J. (2014). A review of nutritional intervention on delayed onset muscle soreness. Part I. *Journal of Exercise Rehabilitation*, *10*(6), 349-356. https://doi.org/10.12965/jer.140179

Leal-Junior, E. C. P., Lopes-Martins, R. Á. B., & Bjordal, J. M. (2019). Clinical and scientific recommendations for the use of photobiomodulation therapy in exercise performance enhancement and post-exercise recovery : Current evidence and future directions. *Brazilian Journal of Physical Therapy*, *23*(1), 71-75. https://doi.org/10.1016/j.bjpt.2018.12.002

Lv, Z.-T., Zhang, J.-M., & Zhu, W.-T. (2020). Omega-3 Polyunsaturated Fatty Acid Supplementation for Reducing Muscle Soreness after Eccentric Exercise : A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *BioMed Research International*, *2020*, 8062017. https://doi.org/10.1155/2020/8062017

Malta, E. de S., de Lira, F. S., Machado, F. A., Zago, A. S., do Amaral, S. L., & Zagatto, A. M. (2019). Photobiomodulation by Led Does Not Alter Muscle Recovery Indicators and Presents Similar Outcomes to Cold-Water Immersion and Active Recovery. *Frontiers in Physiology*, *9*, 1948. https://doi.org/10.3389/fphys.2018.01948

McHugh, M. L. (2011). Multiple comparison analysis testing in ANOVA. *Biochemia Medica*, *21*(3), 203-209. https://doi.org/10.11613/bm.2011.029

Menezes, M. A., Menezes, D. A., Vasconcelos, L. L., & DeSantana, J. M. (2022). Is Electrical Stimulation Effective in Preventing or Treating Delayed-onset Muscle Soreness (DOMS) in Athletes and Untrained Adults? A Systematic Review With Meta-Analysis. *The Journal of Pain*, *23*(12), 2013-2035. https://doi.org/10.1016/j.jpain.2022.05.004

Mosca, R. C., Ong, A. A., Albasha, O., Bass, K., & Arany, P. (2019). Photobiomodulation Therapy for Wound Care : A Potent, Noninvasive, Photoceutical Approach. *Advances in Skin & Wound Care*, *32*(4), 157. https://doi.org/10.1097/01.ASW.0000553600.97572.d2

Mueller-Wohlfahrt, H.-W., Haensel, L., Mithoefer, K., Ekstrand, J., English, B., McNally, S., Orchard, J., van Dijk, C. N., Kerkhoffs, G. M., Schamasch, P., Blottner, D., Swaerd, L., Goedhart, E., & Ueblacker, P. (2013). Terminology and classification of muscle injuries in sport : The Munich consensus statement. *British Journal of Sports Medicine*, *47*(6), 342-350. https://doi.org/10.1136/bjsports-2012-091448

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2012). Recovery in soccer : Part I - post-match fatigue and time course of recovery. *Sports Medicine (Auckland, N.Z.)*, *42*(12), 997-1015. https://doi.org/10.2165/11635270-000000000-00000

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2013). Recovery in Soccer. *Sports Medicine*, *43*(1), 9-22. https://doi.org/10.1007/s40279-012-0002-0

Nelson, N. (2013). Delayed onset muscle soreness : Is massage effective? *Journal of Bodywork and Movement Therapies*, *17*(4), 475-482. https://doi.org/10.1016/j.jbmt.2013.03.002

Nie, H., Madeleine, P., Arendt-Nielsen, L., & Graven-Nielsen, T. (2009). Temporal summation of pressure pain during muscle hyperalgesia evoked by nerve growth factor and eccentric contractions. *European Journal of Pain (London, England)*, *13*(7), 704-710. https://doi.org/10.1016/j.ejpain.2008.06.015

Palsson, T. S., Rubio-Peirotén, A., & Doménech-García, V. (2023). Sleep deprivation increases pain sensitivity following acute muscle soreness. *Sleep Medicine*, *109*, 75-81. https://doi.org/10.1016/j.sleep.2023.06.010

Pearcey, G. E. P., Bradbury-Squires, D. J., Kawamoto, J.-E., Drinkwater, E. J., Behm, D. G., & Button, D. C. (2015). Foam Rolling for Delayed-Onset Muscle Soreness and Recovery of Dynamic Performance Measures. *Journal of Athletic Training*, *50*(1), 5-13. https://doi.org/10.4085/1062-6050-50.1.01

Petrofsky, J., Berk, L., Bains, G., Khowailed, I. A., Lee, H., & Laymon, M. (2017). The Efficacy of Sustained Heat Treatment on Delayed-Onset Muscle Soreness. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine*, *27*(4), 329-337. https://doi.org/10.1097/JSM.0000000000000375

Poppendieck, W., Wegmann, M., Ferrauti, A., Kellmann, M., Pfeiffer, M., & Meyer, T. (2016). Massage and Performance Recovery: A Meta-Analytical Review. *Sports Medicine (Auckland, N.Z.)*, *46*(2), 183-204. https://doi.org/10.1007/s40279-015-0420-x

Querido, S. M., Radaelli, R., Brito, J., Vaz, J. R., & Freitas, S. R. (2022). Analysis of Recovery Methods' Efficacy Applied up to 72 Hours Postmatch in Professional Football: A Systematic Review With Graded Recommendations. *International Journal of Sports Physiology and Performance*, *17*(9), 1326-1342. https://doi.org/10.1123/ijspp.2022-0038

Rodrigues, S., Forte, P., Dewaele, E., Branquinho, L., Teixeira, J., Ferraz, R., Barbosa, T., & Monteiro, A. (2022). Effect of Blood Flow Restriction Technique on Delayed Onset Muscle Soreness : A Systematic Review. *Medicina (Kaunas, Lithuania)*, *58*, 1154. https://doi.org/10.3390/medicina58091154

Royston, J. P. (1982). An Extension of Shapiro and Wilk's W Test for Normality to Large Samples. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, *31*(2), 115-124. https://doi.org/10.2307/2347973

Silva, J. R., Rumpf, M. C., Hertzog, M., Castagna, C., Farooq, A., Girard, O., & Hader, K. (2018). Acute and Residual Soccer Match-Related Fatigue : A Systematic Review and Meta-analysis. *Sports Medicine*, *48*(3), 539-583. https://doi.org/10.1007/s40279-017-0798-8

Soligard, T., Schwellnus, M., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T., Gleeson, M., Hägglund, M., Hutchinson, M. R., Rensburg, C. J. van, Khan, K. M., Meeusen, R., Orchard, J. W., Pluim, B. M., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*, *50*(17), 1030-1041. https://doi.org/10.1136/bjsports-2016-096581

Sonkodi, B., Berkes, I., & Koltai, E. (2020). Have We Looked in the Wrong Direction for More Than 100 Years? Delayed Onset Muscle Soreness Is, in Fact, Neural Microdamage Rather Than Muscle Damage. *Antioxidants*, *9*(3). https://doi.org/10.3390/antiox9030212

Tenberg, S., Nosaka, K., & Wilke, J. (2022). The Relationship Between Acute Exercise-Induced Changes in Extramuscular Connective Tissue Thickness and Delayed Onset Muscle Soreness in Healthy Participants : A Randomized Controlled Crossover Trial. *Sports Medicine - Open*, *8*(1), 57. https://doi.org/10.1186/s40798-022-00446-7

Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and Science in Sports and Exercise*, *48*(3), 543-568. https://doi.org/10.1249/MSS.0000000000000852

Valle, X., Til, L., Drobnic, F., Turmo, A., Montoro, J. B., Valero, O., & Artells, R. (2014). Compression garments to prevent delayed onset muscle soreness in soccer players. *Muscles, Ligaments and Tendons Journal*, *3*(4), 295-302.

Veqar, Z., & Imtiyaz, S. (2014). Vibration Therapy in Management of Delayed Onset Muscle Soreness (DOMS). *Journal of Clinical and Diagnostic Research : JCDR*, *8*(6), LE01-LE04. https://doi.org/10.7860/JCDR/2014/7323.4434

Versey, N. G., Halson, S. L., & Dawson, B. T. (2012). Effect of contrast water therapy duration on recovery of running performance. *International Journal of Sports Physiology and Performance*, *7*(2), 130-140. https://doi.org/10.1123/ijspp.7.2.130

Versey, N. G., Halson, S. L., & Dawson, B. T. (2013). Water immersion recovery for athletes : Effect on exercise performance and practical recommendations. *Sports Medicine (Auckland, N.Z.)*, *43*(11), 1101-1130. https://doi.org/10.1007/s40279-013-0063-8

Wilke, J., & Behringer, M. (2021). Is “Delayed Onset Muscle Soreness” a False Friend? The Potential Implication of the Fascial Connective Tissue in Post-Exercise Discomfort. *International Journal of Molecular Sciences*, *22*(17), Article 17. https://doi.org/10.3390/ijms22179482

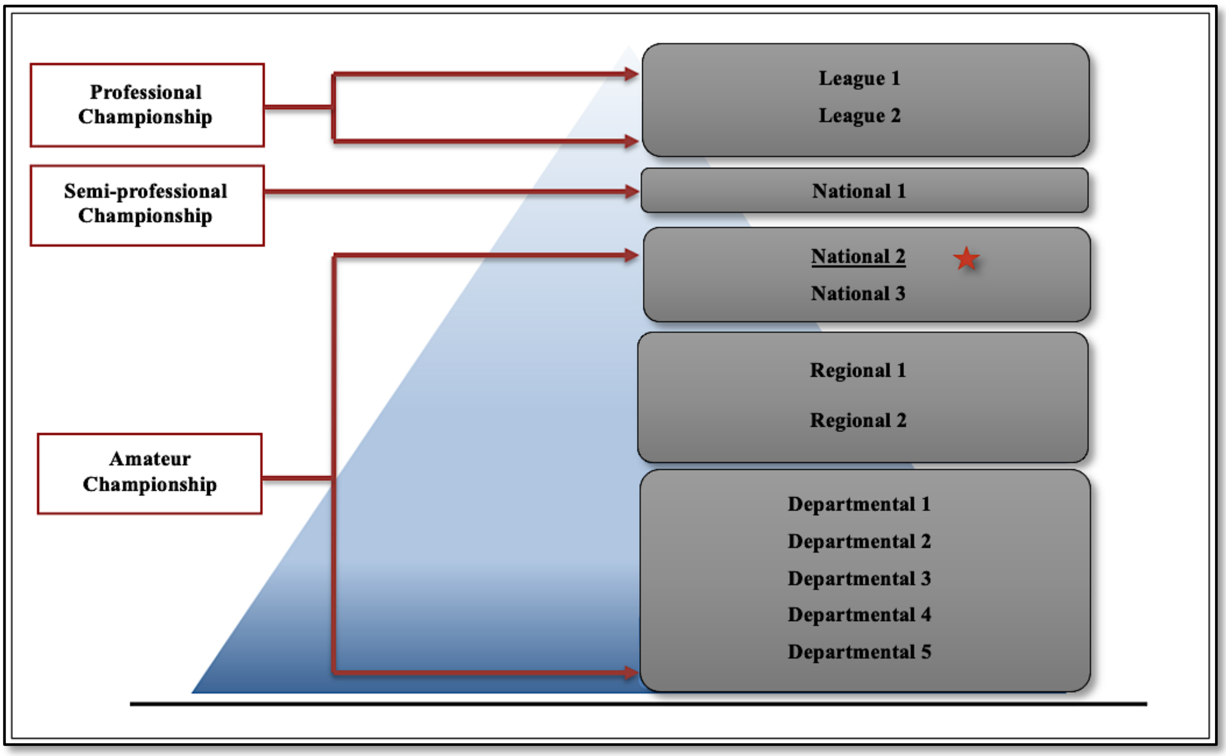
Wiśniowski, P., Cieśliński, M., Jarocka, M., Kasiak, P. S., Makaruk, B., Pawliczek, W., & Wiecha, S. (2022). The Effect of Pressotherapy on Performance and Recovery in the Management of Delayed Onset Muscle Soreness : A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine*, *11*(8), 2077. https://doi.org/10.3390/jcm11082077

Zagatto, A. M., Dutra, Y. M., Lira, F. S., Antunes, B. M., Faustini, J. B., Malta, E. de S., Lopes, V. H. F., de Poli, R. A. B., Brisola, G. M. P., Dos Santos, G. V., Rodrigues, F. M., & Ferraresi, C. (2020). Full Body Photobiomodulation Therapy to Induce Faster Muscle Recovery in Water Polo Athletes : Preliminary Results. *Photobiomodulation, Photomedicine, and Laser Surgery*, *38*(12), 766-772. https://doi.org/10.1089/photob.2020.4803

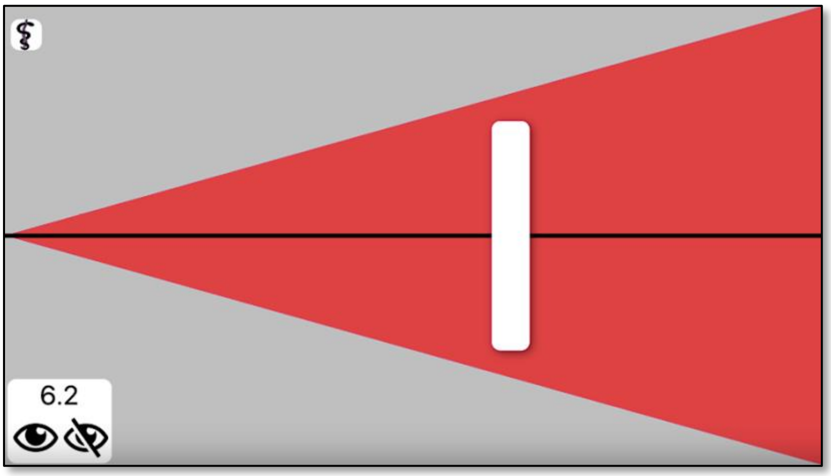
Zein, R., Selting, W., & Hamblin, M. R. (2018). Review of light parameters and photobiomodulation efficacy : Dive into complexity. *Journal of Biomedical Optics*, *23*(12), 1-17. https://doi.org/10.1117/1.JBO.23.12.120901

APPENDICES

APPENDICE A. Pyramidal organisation of French senior football.



APPENDICE B. VAS digital screenshot



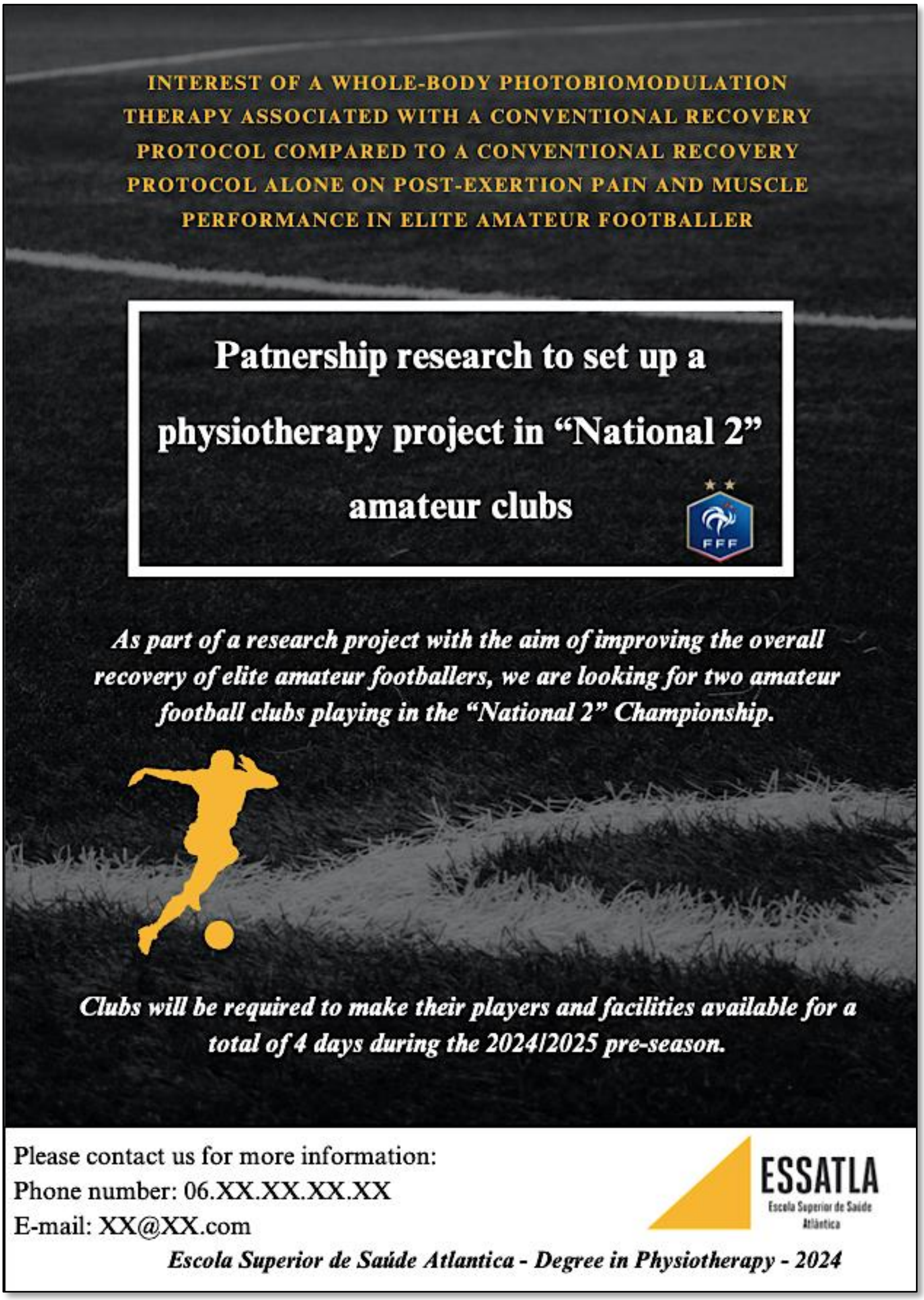
APPENDICE C. Summary of study hypotheses

Hypotheses / Variables	H0	H1 A	H1 B	H1 C	H1 D	H1 E	H1 F	H1 G	H1 H	H1 I	H1 J	H1 K	H1 L	H1 M	H1 N	H1 O	H1 P	H1 Q	H1 R	H1 S	H1 T	H1 U	H1 V	H1 W	H1 X	H1 Y	H1 Z
Muscle pain intensity	θ	+	-	θ	θ	θ	θ	+	-	+	+	+	-	-	-	+	-	+	-	+	-	-	+	θ	θ	θ	θ
Maximum muscle strenght	θ	+	-	θ	θ	+	-	θ	θ	+	-	-	-	+	+	θ	θ	θ	θ	+	-	+	-	+	-	+	-
Maximum muscle power	θ	+	-	+	-	θ	θ	θ	θ	-	+	-	+	-	+	+	-	-	+	θ	θ	θ	θ	-	+	+	-

<u>Legend</u>:

θ (No significant difference) **/ +** (Significant increase) **/ -** (Significant decrease) **/**
H0 (Null Hypothesis) **/ H1** (Alternative Hypotheses)

APPENDICE D. Partnership promotional poster sent to club.



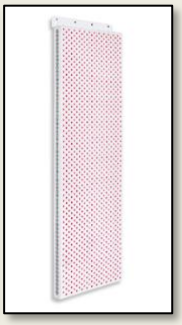
APPENDICE E. Address book of organisations potentially involved in the study.

	Company name	Company headquarters	Contacts	Logo
Organisation responsible for the « National 2 » Championship				
1	***Fédération Française de Football***	*87, Boulevard de Grenelle, 75738 Paris Cedex 15 – France*	Web site: www.fff.fr Phone: 01 44 31 73 00 Fax : 01 44 31 73 73	
« BioLedTherapy® » partner centres (non-exhaustive list)				
2	**Bio Led Therapy**	*40 place du Théâtre Palais de la Bourse 59800 Lille*	Phone : +33 (0)3 62 02 82 20 Mail : contact@bioledtherapy.com	
3	***Sanamente Paris***	*83 rue cambronne 75015 Paris*	Web site: sanamenteparis.com Phone: +33 7 82 33 03 10 Mail: bonjour@sanamenteparis.com	
4	***Sanamente Rennes***	*7 rue de Toulouse 35000 Rennes*	Web : sanamente.fr Phone : 0618871176	
5	***Maison Synèse***	*4 allée du Parmelan, 74370 Epagny Metz-Tessy*	Web site: www.maison-synese.com/ Phone : +33 6 42 59 20 03 Mail : contact@maison-synese.com	
6	***Luminecla***	*12B rue du quai 59800 Lille*	Web site: luminecla.fr Phone : 03 66 76 98 96 Mail : contact@luminecla.fr	
7	***Hotel Grandes Rousses***	*425, route du Signal 38750 Alpe d'Huez*	Web:www.hotelgrandesrousses.com/fr/ Phone : +33 (0)4 76 80 33 11 Mail :contact@hotelgrandesrousses.com	
8	***PBM Bien-être***	*Impasse du Moulin 80700 Roye*	Web site: pbmbienetre.com Phone: 07 49 36 86 73 Mail: contact@pbmbienetre.com	
Designer of the "MyotestPRO®" measuring device				
9	**Myotest SA**	*Rue de la Blancherie 61* *1950 Sion Switzerland*	Phone : 027 456 18 20 Fax : 027 456 18 22 Mail : info@myotest.com	

APPENDICE F. Partnership promotional poster for medical equipment rental.

APPENDICE G. List of equipment required for recovery protocols.

Equipment	Model / Justification
Massage tables (=8) 2 tables for the CTRL group. 6 tables for the EXP group. 	No specific brand will be required, but they must allow players to adopt a comfortable position (reclining backrest) and be easily transportable by investigators (folding).
Massage creams (=2)  1 cream per group.	In order to avoid any bias linked to the presence of active substances that could interact physiologically, the study will finance a neutral massage cream ("Eona Dermoneutre®" for example). The main objective is to facilitate the therapist's manual gliding over the player's skin.
Cold Water Bath (=2) 1 bath per group.  https://www.cryocontrol.fr/gamme-bain-froid-nomade/	This is a mobile immersion cryotherapy unit (inflatable structure) of the "Cryocontrol®" brand. It's easy to use and requires very little space (D160cm / H70cm). Thanks to its motorised hydraulic system, the water can be cooled to between 8 and 12°C, maintaining the optimum temperature for use. Its two-person capacity allows athletes to recover quickly and easily and can be used collectively during competitions or pre-season training.
Hot Water Bath (=2)  1 bath par group.	No particular model of "spa" will be recommended, but the dimensions of the Inflatable structure should be similar to those of the cold water pool and therefore have the same capacity (two persons). It should also be able to heat the water and maintain a constant temperature of at least 38°C. Financed by the study and currently very popular on the market, it doesn't seem difficult to find a suitable model.
Water Thermometer (=4) / **Solar power meter** (=1)  2 thermometers per group. 1 Solar power meter for the EXP group. 	As a precautionary measure, and to avoid bias due to variations in bath temperature or light irradiation, the study will also finance 4 standard water thermometers and 1 solar power meter to monitor these parameters regularly during the intervention protocol.

Whole-body PBMT devices (=4) (For the EXP group only)   https://bioledtherapy.com/photobiomodulation/appareils-de-photomodulation/pbm-1200/	The model selected ("**PBM 1200 LEDs**"), manufactured by **BioLedTherapy®**, will provide whole-body exposure thanks to a light panel measuring 1.65 metres long and 55 cm width. It is composed of 600 red LEDs at 660 nm and 600 near-infrared LEDs at 850 nm, giving a total of 1,200 high-quality LEDs with an irradiation capacity (described later) in line with scientific recommendations. Its mobile stand allows it to be used in a horizontal (or vertical) position at a height of between 1 m and 1.50 m. The removable nature of this model (compared to a PBMT cabin) makes it easier to recruit and install the device. It makes the project more achievable and offers an application that can be reproduced by all clubs in current practice. However, if difficulties persist to recruit this device, other models of the same type are commercially available and could be selected for the experiment.

APPENDICE H. Free and informed consent form.

Free and Informed Consent Form

I, the undersigned ...., declare that I freely and knowingly agree to participate as a subject in the study entitled:

« Interest of a Whole-body photobiomodulation therapy associated with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exertion pain and muscle performance in elite amateur footballer».

Principal investigator: BRANDO Enzo (Phone: 06.X.X.X.X)

Aim of the study: The general aim of the study is to compare the effect of whole-body photobiomodulation combined with a conventional recovery protocol compared to a conventional recovery protocol alone on post-exercise recovery in elite amateur footballers affected by Exercise-Induced Muscle Dammage.

Participant commitment: The study consists of a common intensive training session for all participants to induce soreness. This will be followed by a specific recovery protocol, which will vary according to the allocation of clubs (Massotherapy + Contrast Water Therapy or Massotherapy + Contrast Water Therapy + whole body PBM). An assessment of pain, strength and muscle power is carried out before and after the intervention protocol.

The participant declares that he meets the eligibility criteria (set by the principal investigator) and agrees to comply with them throughout the study. The participant also agrees to follow some additional guidelines related to the intervention protocol in order to limit study bias: During the 4 days of the trial:

1) Maintain as much relative rest as possible, apart from study-related interventions.

2) Keep properly hydrated with at least 2 liters of water per day.

3) Try to get a full night's sleep (ideally 8 hours).

Commitment of the Principal Investigator: The principal investigator commits to conduct this research in accordance with ethical and deontological principles, to protect the physical, psychological and social integrity of individuals throughout the research, and to ensure the confidentiality of the information collected. He also commits himself to provide participants with all the necessary support to mitigate any negative effects that may result from their participation in this research.

Freedom of the participant: Consent to continue the research may be withdrawn at any time without giving a reason and without any liability or consequence. Answers to the questions are voluntary and failure to answer will have no consequences for the subject.

Participant information: The participant will have the opportunity to obtain additional information about this study from the principal investigator, within the constraints of the research plan.

Confidentiality of information: All information about participants will be kept anonymous and confidential. Data processing is not nominative and is therefore not covered by the Data Protection Act (right of access and rectification not allowed). As this research is purely psychological in nature, it is not covered by the Huriet-Sérusclat law on the protection of individuals in biomedical research. The transmission of information about the participant for expert appraisal or scientific publication will also be anonymous.

Deontology and ethics: The promoter and the principal investigator undertake to maintain absolute confidentiality and professional secrecy with regard to all information concerning the participant (Title I, Articles 1, 3, 5 and 6 and Title II, Articles 3, 9 and 20 of the French Code of Ethics of Psychologists).

Made in………. On ……… Signatures: The participant The Principal Investigator

APPENDICE I. Description of the EIMD generator training.

EIMD training protocol (Club A **&** Club B)

Step 1
(≈ 20 min)

« 11+ »
Warm-up Program

It is divided into 3 parts: (Annex K)

Part 1 **(**8 min**)** → **Running** exercices.

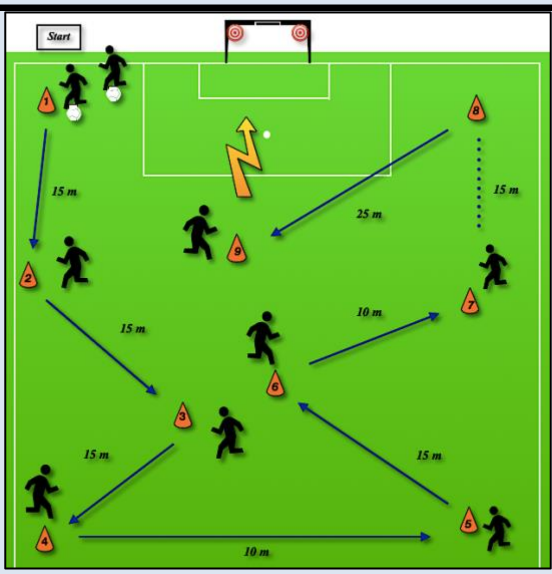
Part 2 **(**10 min**)** → **Strenght, Plyometric** and **balance** exercices (« Level 3 »).

Part 3 **(**2 min**)** → **Running** exercices (High intensity).

Step 2
(≈ 30 min)

Physical exercise with ball

« Circuit passe et suit »



→ The exercise will be set up identically on both halves of the pitch (see opposite). For this step, the 18 players will be randomly divided by the investigators into two groups of 9 players each.

From a quantitative point of view, it will be planned for each player to complete 8 full laps of the circuit, organised as follows: **4 full laps of the circuit → 2 minutes of passive recovery → 4 full laps of the circuit.**

It seems relevant to set a number of laps per player beforehand. This will standardise the physical effort, making the number of passes, runs and shots made by each of the 18 participants identical.

Circuit instructions and description:

→ From the "start" position (cone no. 1), the player must pass the ball to the player at the next cone. He then goes to the cone no. 2 to take the place of the player who received the ball. The player at cone no. 2 then passes the ball to the next player and goes to the cone no. 3. This simple concept is repeated until the 7th cone.

The player at cone no. 7 receives the ball and runs 15 metres with the ball at his feet. He then goes around the outside of cone no. 8 and passes the ball to the player on the cone no. 9. The player on the last marker controls the ball and then takes a shot (about 18 metres from the goal) at one of the two targets fixed in the goal. He then returns with the ball to the "start" position.

- → **To define a complete lap, each player must reach the cone which he initially occupied.**
- → **When the movement of the ball completes a full lap of the circuit, the second player at the "start" position can begin the next lap.**
- → **The ball must be passed with the inside of the foot, and the shoot at goal must be made using the dorsal side of the foot.**
- → **The runs from one cone to the next should be done with a high level of intensity. It will be explained to the players that the aim is not to "sprint" but to run at a steady pace.**

<table>
<tr>
<td>

Step 3

(≈ 30 min)

Physical exercice without ball

Muscle-strengthening phase

(Lower limb)

+

Running workout

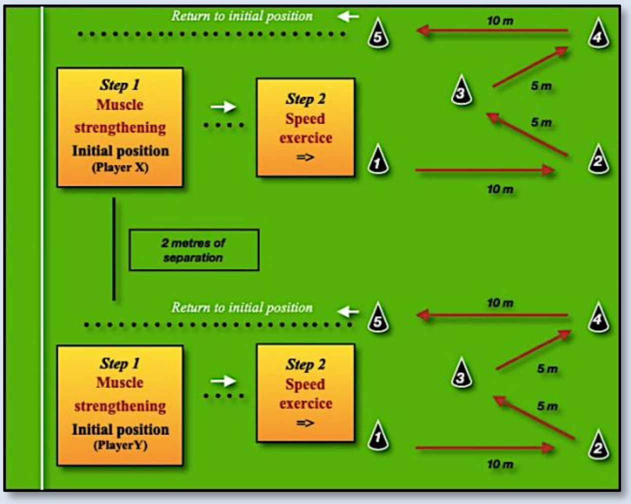
</td>
<td>

→ Positioned in-line at the edge of the pitch, a distance of 2 metres will separate the players to ensure that they can easily perform the following 4 muscle-strengthening exercises according to a precise qualitative and quantitative description: (Appendix J)

- **« Squat » (Exercice 1)**
- **« Deadlift » (Exercice 2)**
- **« Jumping Lunges » (Exercice 3)**
- **« Burpees » (Exercice 4)**

Thus, exercises **1** to **4** will be performed successively for **5 sets of 10 repetitions** each.

A passive recovery period of 3 minutes will be allowed between each exercise.



→ At the end of each set, the player will continue directly in front of him on a running workshop with change of supports (see above). This speed exercise will be performed with a maximal running intensity.

Then, the subject will be allowed to walk back to their initial position, where they will have 30 seconds to recover before starting a new series of muscle-strengthening exercises. Therefore, each of player will perform the running exercise 20 times.

</td>
</tr>
<tr>
<td>

Step 4

(≈ 20 min)

« Match with themes »

9 vs 9

</td>
<td>

→ For the final stage of the protocol, a confrontation between two teams of 9 players will take place on half a field. Without any influence on the study, the division of the 18 players into two teams will be carried out according to a random choice by the investigators (different coloured chasubles will be distributed).

The exercise will take place as follows:

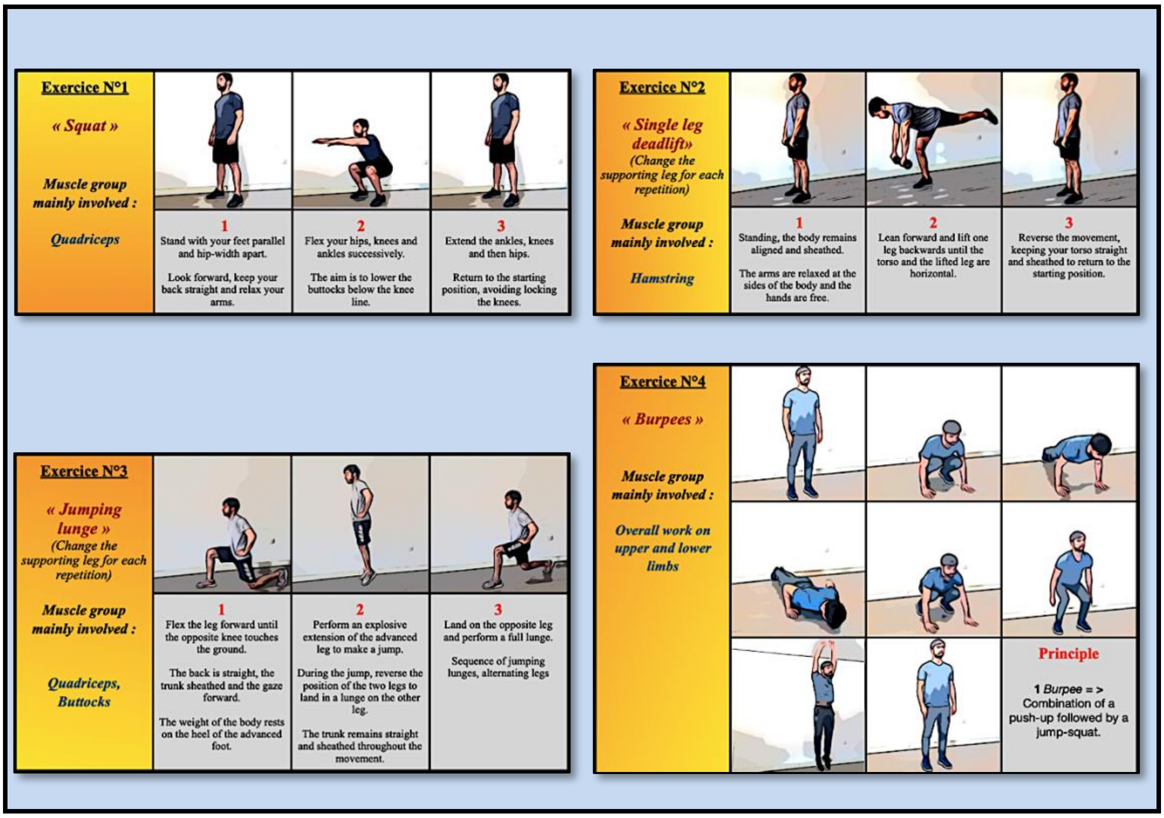
- **Phase 1:** During this first phase, the aim will be to keep possession of the ball by passing it around without the opposing team intercepting the passes. A point will be scored when the team manages to pass the ball to all its players, without any interceptions by the opposing players (**Playing time** → ***10 minutes***).
- **Passive recovery :** (***3 minutes***).
- **Phase 2:** In this second phase, the players will be authorised to score a point by blocking the ball with their foot on the line that defines the width of the opponent's court. In order to score a point, all players of the team should be involved by passing the ball without being intercepted by the opponent. (**Playing time** →***10 minutes***).

</td>
</tr>
<tr>
<td colspan="2">

18 Players – 3 Investigator physiotherapists –*Total estimated time: 1 hour 40 minutes*

</td>
</tr>
</table>

APPENDICE J. Description of the muscle-strengthening phase of the training protocol (Step 3)



APPENDICE K. Summary of conventional recovery protocol.

Conventional recovery protocol (Club A → 30 minutes per player)

Part 1

Massotherapy

Lower Limb

Total duration : ***15 minutes***

(Bezuglov et al., 2021 ; Poppendieck et al., 2016)

Techniques :

Effleurage –Deep gliding pressure – Kneading (Poppendieck et al., 2016)

Massage cream : *Neutral*

Step 1 : *Supine position* **(7 min 30 sec – Quadriceps)**

→ 3 min 45 on the left lower limb + 3 min 45 on the right lower limb.

→ Disto-proximal movements on the anterior thigh.

Position

The patient is positioned supine with the backrest inclined to allow him to find a comfortable position.

A table cushion is placed at the level of the popliteal fossa to relieve the joints and obtain an optimal drainage position.

A member's description of the process	
Effleurage with both hands	*30 seconds*
Alternation of deep sliding pressure / kneading	*2 min 45 sec*
Effleurage with both hands	*30 seconds*

Step 2 : *Prone position* **(7 min 30 sec – Triceps Surae & Hamstrings)**

→ 3 min 45 on the left lower limb + 3 min 45 on the right lower limb.

→ Disto-proximal movements from the distal end of the Triceps Surae to the proximal end of the Hamstring.

Position

The player is positioned in a prone position. A table cushion is placed under the ankles to relieve the joints and put the limbs in an optimal drainage position.

A member's description of the process	
Effleurage with both hands	*30 seconds*
Alternation of deep sliding pressure / Kneading	*2 min 45 sec*
Effleurage with both hands	*30 seconds*

Part 2

CWT

Total duration : ***15 minutes***

(Higgins et al, 2017)

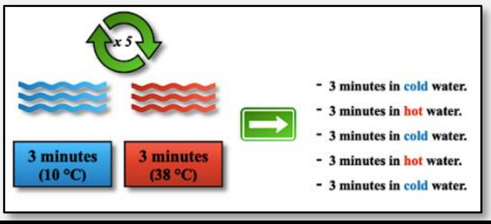
Water baths temperature:

Cold Water (10° C) – Hot Water (38°C) (Higgins et al, 2017)

Immersion position

The capacity of the baths will allow the subjects to adopt a comfortable position. The players in underwear are seated, immersed up to the umbilicus, with the knees unlocked (flexion ~ 10°) and the hips slightly flexed.

This position is maintained with the elbows resting on the edge of the structure. Compression of the various venous trunks of the lower limb (due to incorrect positioning) can thus be avoided.



Chronology of the subject's immersion

Players will complete successive transitions by an immersion in cold water (Cochrane, 2004).

Procedure : Two physiotherapists will be in charge of the massage therapy while a third investigator will supervise the CWT (during the protocol, the positions will be rotated between the physiotherapists). The first two players will start with the massage therapy (1:1 ratio with the investigator), and will then be immersed in the same bath during successive CWT immersions. As soon as the massage tables are available, two other players will be able to move in and begin the protocol. This will optimise the total duration of the conventional recovery protocol and, above all, avoid players having to wait between the two therapies to which they will be subjected.

Total estimated duration : 2 hours 30 minutes

APPENDICE L. Summary of experimental recovery protocol.

Experimental recovery protocol (Club B → 30 minutes per player)

Part 1

Massotherapy

Lower limb

Total duration: *9 minutes*

(Poppendieck et al., 2016)

Techniques:

Effleurage –Deep gliding pressure – Kneading

(Poppendieck et al., 2016)

Massage cream : *Neutral*

Step 1 : *Supine position* (4 min 30 sec – Quadriceps)

→ 2 min 15 on the left lower limb + 2 min 15 on the right lower limb.

→ Disto-proximal movements on the anterior thigh.

Position	A member's description of the process	
The patient is positioned supine with the backrest inclined to allow him to find a comfortable position. A table cushion is placed at the level of the popliteal fossa to relieve the joints and obtain an optimal drainage position.	Effleurage with both hands	*15 seconds*
	Alternation of deep sliding pressure / kneading	*1 min 45 sec*
	Effleurage with both hands	*15 secondes*

Step 2 : *Prone position* (4 min 30 sec – Triceps Surae & Hamstrings)

→ 2 min 15 on the left lower limb + 2 min 15 on the right lower limb.

→ Disto-proximal movements from the distal end of the Triceps Surae to the proximal end of the Hamstring.

Position	A member's description of the process	
The player is positioned in a prone position. A table cushion is placed under the ankles to relieve the joints and put the limbs in an optimal drainage position.	Effleurage with both hands	*15 seconds*
	Alternation of deep sliding pressure / kneading	*1 min 45 sec*
	Effleurage with both hands	*15 seconds*

Part 2

CWT

Total duration : *6 minutes*

(Versey et al., 2012)

Water baths temperature:

Cold Water (10° C) – Hot Water (38°C)

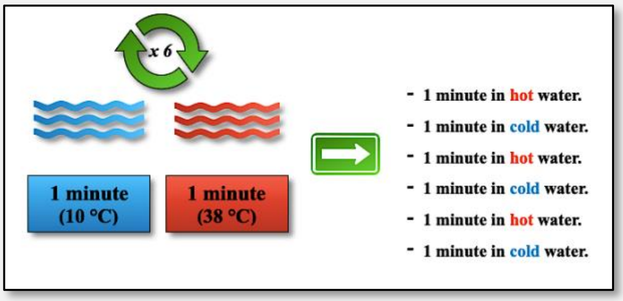
(Higgins et al, 2017)

Immersion position

The capacity of the baths will allow the subjects to adopt a comfortable position. The players in underwear are seated, immersed up to the umbilicus, with the knees unlocked (flexion ~ 10°) and the hips slightly flexed.

This position is maintained with the elbows resting on the edge of the structure. Compression of the various venous trunks of the lower limb (due to incorrect positioning) can thus be avoided.

Chronology of the subject's immersion



In this way, the immersion times in hot and cold water will be identical (Higgins et al, 2017) and players will complete successive transitions by an immersion in cold water (Cochrane, 2004).

Part 3

Whole-body PBM Therapy

« PBM 1200 LEDs » model

Total duration : ***15 minutes***

Checking the irradiance of the device.

Chronology of irradiation

Step 1 : ***Anterior irradiation*** ***6 minutes***	**Step 2** : ***Posterior irradiation*** ***9 minutes***

Position of the subject

The subject will be positioned in underwear under the whole-body PBMT device to allow full-body exposure.

The subject will first adopt a comfortable supine position (on a massage table) with a cushion positioned under the popliteal fossa for anterior irradiation. After 6 minutes of treatment, he will move to a prone position and will place the cushion under the ankles to allow posterior irradiation for 9 minutes.

Precautions

- Protective glasses will be issued and must be worn by players.
- All jewellery will be removed

- The investigator will observe the condition of the skin before the start of the treatment to check that there are no wounds or injuries that could have been caused by the intensive training.
- The investigator will be asked to monitor the subject's sensations regularly throughout the treatment.

Device irradiation parameters

Based on scientific guidelines for sports practice *(Leal-Junior et al., 2019)*

Light source : 1200 LEDs (600 Red / 600 Near Infrared) – Athermic.

Wavelengths : **660 nm / 850 nm** in simultaneous association.

Mode : **Continuous.**

LED power : 5 Watts (W)

Irradiance of the device : **135 mW/cm² at 13 cm** (100 mW/cm² at 15 cm)

The initial irradiance has been increased by reducing the distance between the light source and the skin (law of the inverse square of the distance) to optimise total exposure time.

Irradiation time: : **15 minutes (**6 minutes + 9 minutes**)**

The anterior and posterior irradiation times have been calculated according to the dose we wish to deliver to the different muscle groups of the lower limb (Appendix M)

→ Quadriceps **(60 Joules)** / Hamstrings **(60 Joules)** / Triceps Surae **(45 Joules).**

Localisation : Whole-body.

Irradiation technique : Stationary / At a distance of **13 cm** from the skin (the distance between the light source and the skin can be adjusted using the device's removable support).

Procedure :

Two physiotherapists will be in charge of the massage therapy, while a third investigator will supervise the CWT and the whole-body PBMT (during the protocol a rotation between the physiotherapists can be envisaged). All resources (human and material) will allow the players to be treated in pairs without interruption (2 tables for therapeutic massages and 4 tables for PBM therapy).

The first two players will start with massage therapy (1:1 ratio with the investigator), then, they will be immersed in the same pool during the successive CWT immersions, and finally they will individually position themselves on one of the tables placed under the PBMT device.

When the two tables reserved for massages become available, the next two players will be able to install themselves and begin the protocol. This arrangement optimises the overall duration of the experimental recovery protocol and, above all, avoids players having to wait between the three therapies to which they will be subjected. ***Total estimated time: 1 hour 40 minutes***

APPENDICE M. Calculation details of Whole-body PBMT duration.

Duration calculation

To deliver a dose equivalent to 60 Joules to the Quadriceps and Hamstrings and a dose equivalent to 45 Joules to the Triceps Surae with an initial irradiance of 135 mW/cm², the theoretical exposure time required for each muscle group must be calculated using the following physics formula:

$$\textbf{Time (s)} = \frac{Energy\ (J)}{Irradiance\ (W/cm^2) \times Surface\ aera\ (cm^2)}$$

1. **Quadriceps:** (Estimated average surface area = 1200 cm² for both legs)

Time (s) = $\frac{60\ J}{0.135\ W/cm^2 \times 1200\ cm^2}$ ≈ 370.37 s ≈ **6 minutes**

→ *Whole-body anterior irradiation for **6 minutes** would therefore deliver a dose of **60 joules** to the **quadriceps.***

2. **Hamstring**: (Estimated average surface area = 800 cm² for both legs)

Time (s) = $\frac{60\ J}{0.135\ W/cm^2 \times 800\ cm^2}$ ≈ 555.56 s ≈ **9 minutes**

3. **Triceps Surae**: (Estimated average surface area = 600 cm² for both legs).

Time (s) = $\frac{45\ J}{0.135\ W/cm^2 \times 600\ cm^2}$ ≈ 555,56 s ≈ **9 minutes**

→ *Whole-body posterior irradiation for **9 minutes** would therefore deliver a dose of **60 joules** to the **hamstrings** and **45 joules** to the **triceps surae.***

Fluence

Fluence (J/cm²) is defined as the total light energy delivered per unit area.

Fluence (J/cm2) = Irradiance (W/cm2) × Time (s)

Step 1: (Anterior irradiation**)**

Fluence (J/cm2) = 0.135 (W/cm2) × 370.70 (s) ≈ **50 J/ cm²**

Step 2: (Posterior irradiation**)**

Fluence (J/cm2) = 0.135 (W/cm2) × 555,56 (s) ≈ **75 J/cm²**

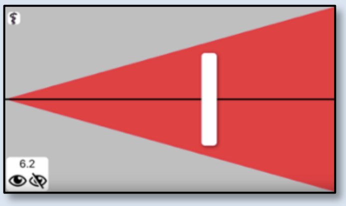
APPENDICE N. Summary of assessment protocol.

Assessment protocol (Club A **&** Club B**)**

Step 1

Evaluation of muscle pain intensity

Digital VAS



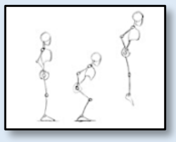
« *EVA - Échelle Visuelle Analogiqu* » application installed on smartphone.

- **Self-assessment** by the subject of muscle pain intensity in the lower limbs.
- Move the mobile cursor along a limited horizontal line across the touch screen.
- Left end (« No pain ») - Right end (« Maximum pain imaginable »).
- The result value is displayed directly on the smartphone screen.

Step 2

Evaluation of maximal muscular strength and power

« MyotestPRO® » accelerometer



Assessment of the muscle performance of the lower limbs generated during a vertical jump: **Countermovement Jump (CMJ)**

Test modalities

The subject's equipment, the installation of the material as well as the directives for optimal execution of the jump will be specified in order to standardise the evaluation and to limit errors in the recording of the apparatus. (Annex L).

Warm-up phase (before the test)

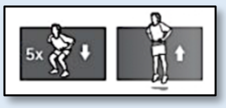
It follows the manufacturer's recommendations:

- Low intensity jogging for 10 minutes (120 bpm).
- 2 x 5 repetitions of CMJ at low intensity.
- 2 x 5 repetitions of CMJ at medium intensity
- 2 x 3 repetitions of CMJ at high intensity.

A one-minute recovery period will be respected between each set and a three-minute recovery period will be respected at the end of the warm-up before the test.
https://www.yumpu.com/en/document/read/33627579/quick-start-guide-en-myotest

Test execution and data collection

→ **5 repetitions of CMJ** seeking the maximal height of the jump (Annex L).



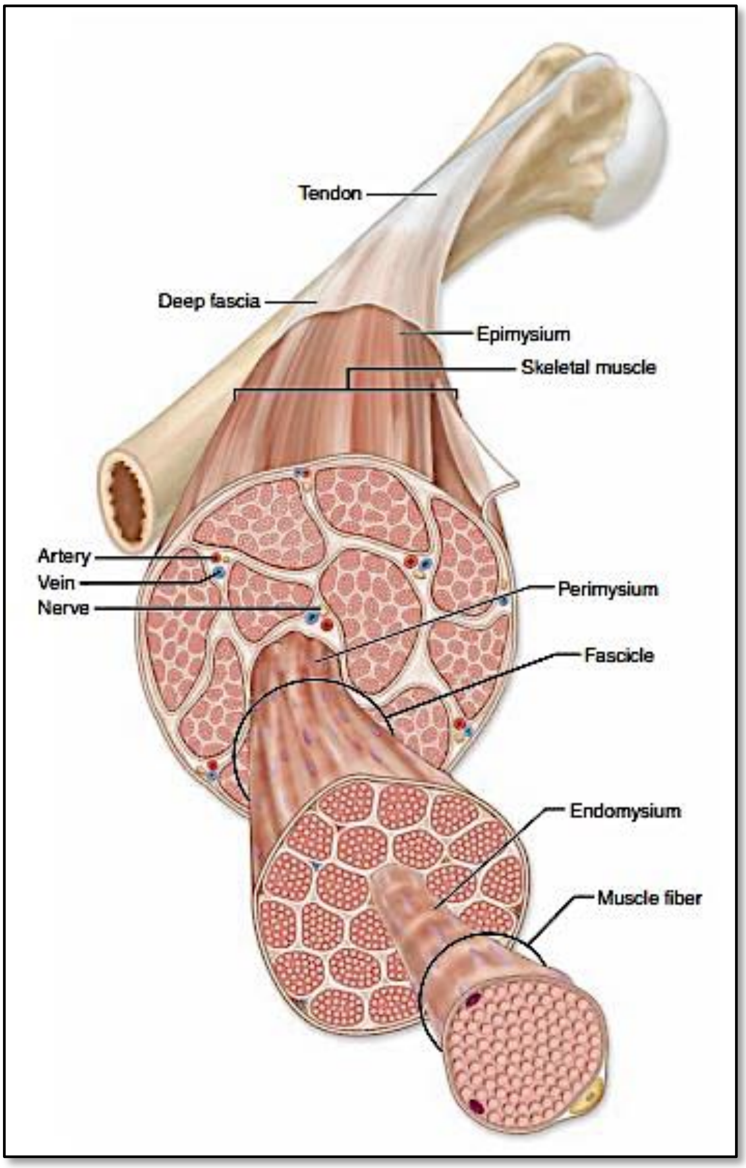
At the end of the test, the results will be automatically displayed on the device's screen. The execution speed of the movement (cm/s), the height of the jump (cm) as well as the **muscle strength (N/Kg)** and **power (W/Kg)** developed during the CMJ will be notified. The results displayed on the screen have been calculated by averaging the three best CMJ repetitions performed by the subject (the height of the jump being the reference parameter of the device).

Initial collection (**Day 1**) - **Final** collection (**Day 4**) / Performed in a **blinded** process by **independent assessors.**

ANNEXES

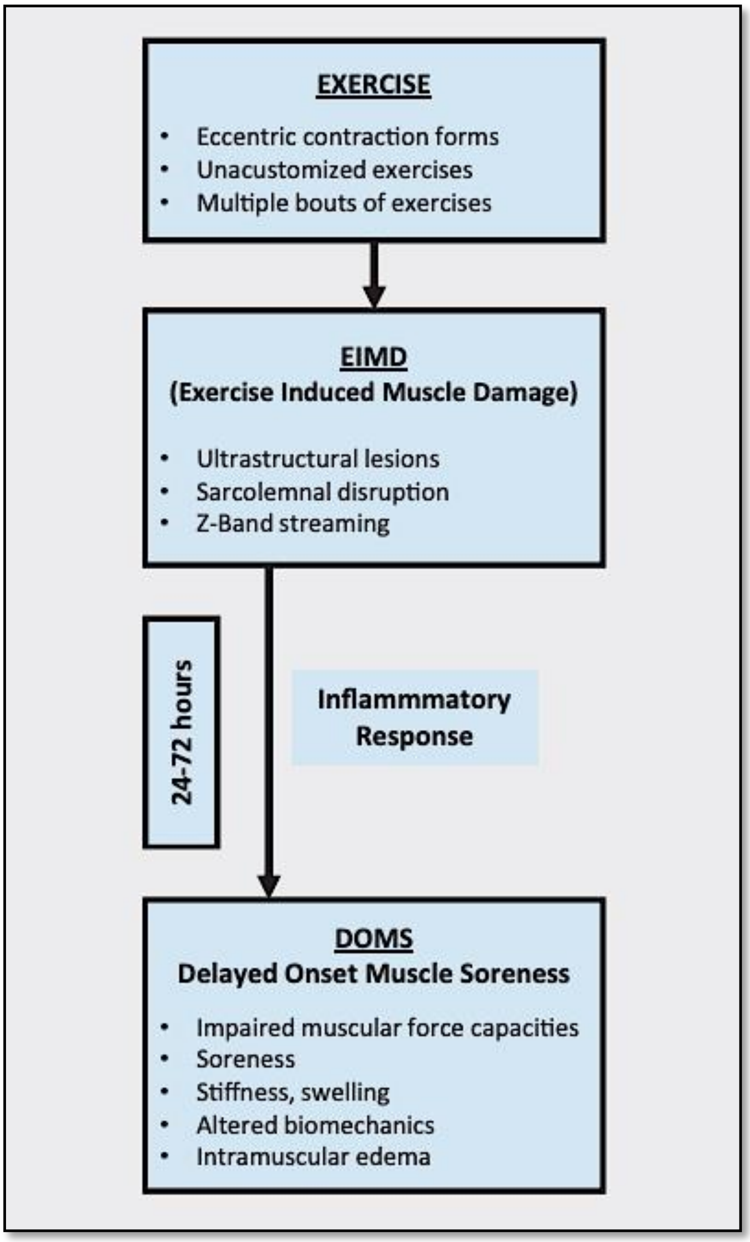
ANNEX A. Structural organisation of skeletal muscle.

(Source : https://doctor2017.jumedicine.com/wp-content/uploads/sites/7/2018/01/muscle-lecture.pdf)



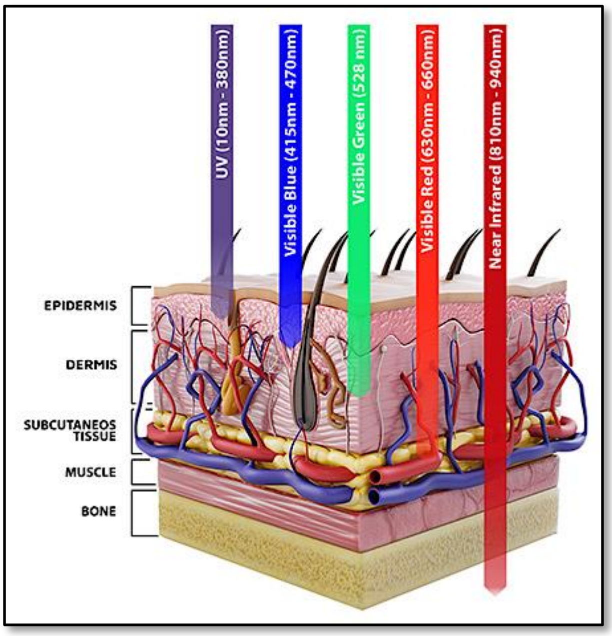
ANNEX B. The pathophysiological mechanism of EIMD and DOMS.

(Heiss et al., 2019)



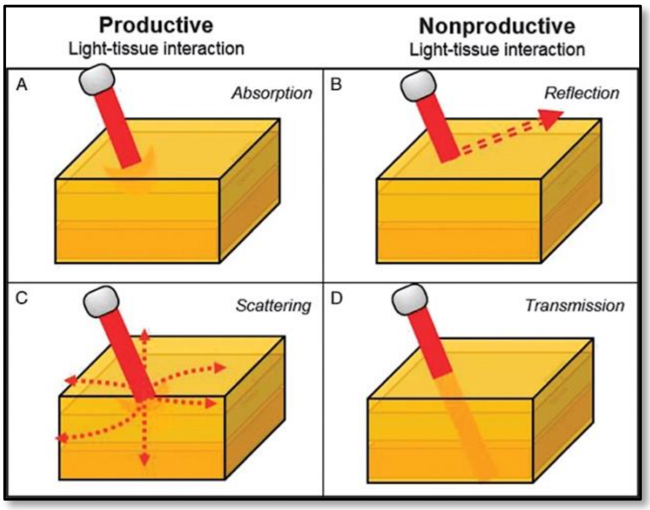
ANNEX C. Depth of light irradiation according to wavelength.

(Source : https://arrcled.com/photobiomodulation/)



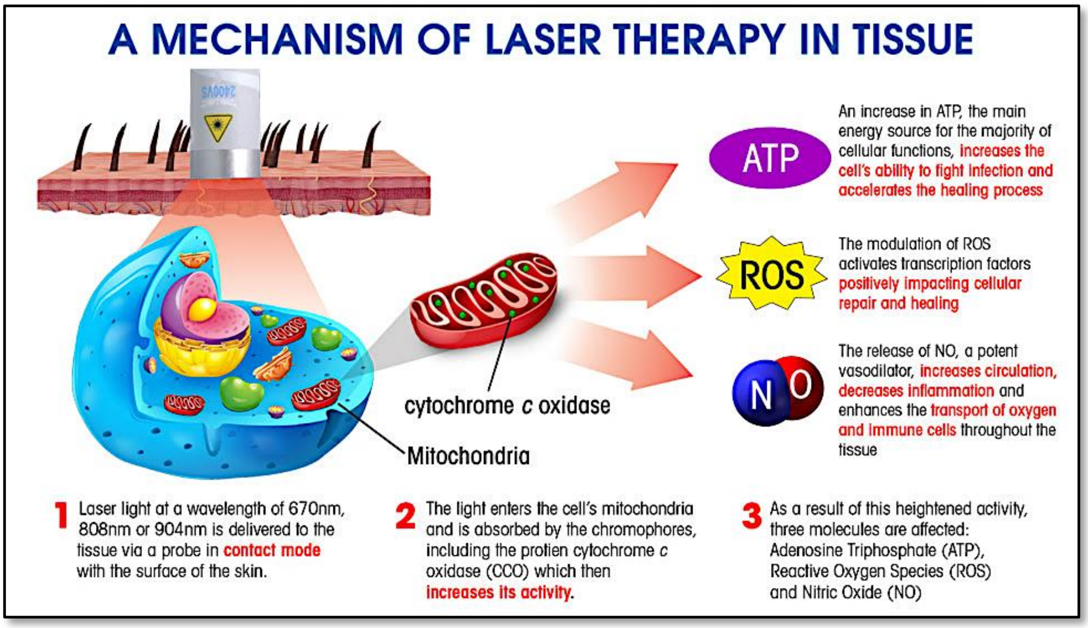
ANNEX D. “Light-biological tissue” interactions and clinical effectiveness.

(Mosca et al., 2019)



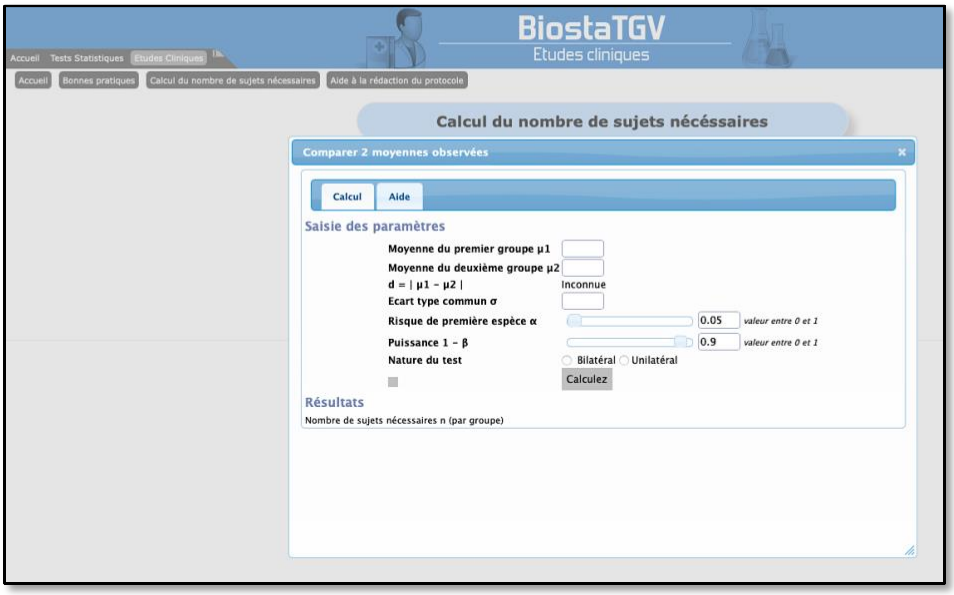
ANNEX E. Physiological mechanism of interaction between infrared radiation and biological tissue.

(Source : https://tahoelaserpt.com/novothor)



ANNEX F. BiostatGV® software interface.

(Source : https://biostatgv.sentiweb.fr)



ANNEX G. « MyotestPRO® » measuring device.

(Source : https://www.yumpu.com/fr/document/read/30058742/lappareil-myotest-pro)

ANNEX H. List of French clubs in the "National 2" championship.

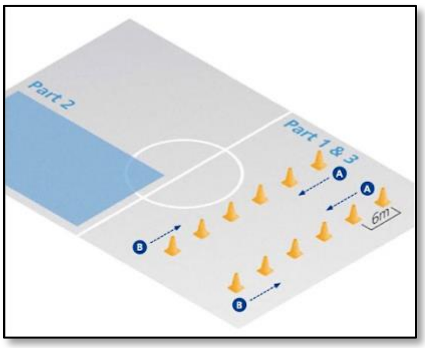
(Source : https://www.fff.fr/competition/engagement/407708-n2/phase/1/index.html)

N2 FFF

GROUPE A	GROUPE B	GROUPE C	GROUPE D
ANDRÉZIEUX-BOUTHÉON FC	ANGERS SCO 2	AF VIROIS	AJ AUXERRE 2
AS CANNES	ANGOULÊME CHARENTE FC	AS BEAUVAIS OISE	AS FURIANI AGLIANI
AUBAGNE FC	AVOINE O. CHINON CINAIS ou TOURS FC	DINAN-LÉHON FC	ASC BIESHEIM
ÉTOILE FRÉJUS ST-RAPH. FC	BERGERAC PÉRIGORD FC	EA GUINGAMP 2	ENT. FEIGNIES AULNOYE FC
FC BOURGOIN JALLIEU	BLOIS FOOT 41	FC BORGO	FBBP 01
FC CHAMALIÈRES	BOURGES FOOT 18	FC CHAMBLY OISE	FC 93 BBG
HYERES FC	FC LIBOURNE	FC LORIENT 2	FC FLEURY 91
JURA SUD FOOT	LA ROCHE / YON VF	FCM AUBERVILLIERS	FCSR HAGUENAU
LE PUY FOOT 43 AUVERGNE	OLYMPIQUE SAUMUR FC	RACING CLUB DE FRANCE F.	OLYMPIQUE SAINT-QUENTIN
OLYMPIQUE ALÈS-EN-CÉVENNES	PARIS 13 ATLETICO	STADE BRIOCHIN	RACING BESANÇON
RC PAYS DE GRASSE	SO ROMORANTIN	US BOULOGNE CO	SR COLMAR
SC TOULON	ST-PRYVÉ ST-HILAIRE FC	US GRANVILLE	UF MACONNAIS
THONON EVIAN GG FC	TRÉLISSAC FC	US SAINT-MALO	US CRÉTEIL LUSITANOS
TOULOUSE FC 2	VENDÉE LES HERBIERS F.	VOLTIGEURS CHÂTEAUBRIANT	WASQUEHAL FOOT

ANNEX I. « 11+ » warm up programme (Step 1 of the training protocol).

(Source: ACL injury prevention with FIFA 11+. (2017, mai 7). *Dr. Bu Balalla*. https://kneesurgerysydney.com.au/preventing-acl-injuries-with-the-fifa-11-program/)



ANNEX J. Vertical Jump application guidelines (CMJ).

(Source : https://www.yumpu.com/en/document/read/33627579/quick-start-guide-en-myotest)

myotest
performance measuring system

4. JUMP - CMJ

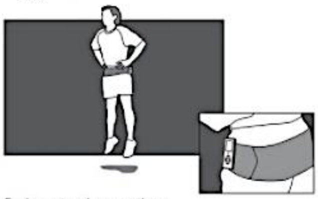
Objectives of the test:
Measurement of the height of the jump

Execution:
5 repetitions aiming for the maximum height.

Sequence:

1. Start the Myotest by keeping the "ON/OFF" key pressed until the logo appears.
2. Select the "CMJ jump" test and check that body weight is correct, otherwise adjust it.
3. Place the Myotest on the belt and press "ENTER".
4. Start in the standing position, hands on your hips, look straight ahead and stand still.
5. At the short beep, make a free lunge movement (bend your knees) and jump as high as possible while keeping your hands on your waist. The landing should be soft and smooth.
6. After landing, return to the standing position and, while standing still, await the next beep before repeating the jump.

After 5 repetitions, the double-beep signals the end of the test



Equipment and preparation:

- Shoes with hard soles
- Hard ground
- Warm up (see user instructions p.1).
- Familiarize yourself with the movement prior to the test (dry-runs).
- Position the Myotest on the belt: perfectly straight, always on the left.

13

Errors:
Errors in execution are signaled by a deep beep. The Myotest tolerates two errors before automatically aborting the test so as to not invalidate the results.
An error message is generated if the following points are not observed:

1. Execute the movements energetically so that the Myotest can clearly detect them.
2. Stay still during the waiting phases for the beeps.
3. Respect the rhythm of the beeps and carry out the jump upon their signal.
4. The countermovement (lunge) should be well emphasized.
5. Perform all of the 5 repetitions.

Results:
The results are automatically displayed on the screen after the test. They show the average of the three best repetitions (the height is taken as the reference). The arrows indicate your progression with respect to the average of your last three tests.

Your results	
Height	39.1 cm ▾
Power	62.81 W/kg ▾
Force	30.23 N/kg ▾
Velocity	276 cm/s ▾

The **height** is given in centimeters. The **power** output and **force** values are taken during the countermovement phase and are given relative to body weight, in watts and newtons per kilogram respectively. This allows the comparison of your performances with those of other users. The **velocity** is an absolute value given in centimeters per second.

Note: the movement is free which means that a change in the bending and straightening path considerably influences the power and force values. We suggest that height is used as the most relevant value if you are not monitored by an expert.

The test results are stored in the memory of the device; you can thus access them at all times. Log on to **www.myotest.com** to store your tests and compare your results with those of other sportspeople and elite athletes.

www.myotest.com
14