Dissertation

The effects of two different Cryotherapy methods on the recovery of physical performance in trained athletes

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Keywords: CRYOTHERAPY; COLD WATER IMMERSION; WHOLE BODY CRYOTHERAPY; ATHLETES**;** FATIGUE; RECOVERY;

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Abstract

Introduction: Cryotherapy, although established as effective in attenuating inflammation and tissue damage, it's still viewed with controversy in specific performance sport context. It has been shown by some authors to be a potentially effective tool for recovery after intensive exercise but further research is required.

Objectives: This study examined the eventual physiological and physical benefits of Cold Water Immersion (CWI) and Whole Body Cryotherapy (WBC) on attenuating exercise induced fatigue in athletes.

Material and Methods: Forty males athletes (40) were randomly allocated into three groups, each with a different recovery strategy (CWI, WBC and PR), performed an acute high stress fatigue protocol of 300 repetitions at 80% body weight, of leg press, in a 3:1 eccentric/concentric contraction ratio. Afterwards, each group performed the given recovery modality: Cold water immersion (10ºC, 10 minutes); Whole body Cryotherapy (-190ºC, 2 minutes); Passive Recovery (Control). The following performance parameters were evaluated prior to exercise and later at 24h and 48h after exertion: Maximum Isometric Voluntary Contraction (MIVC) of the quadriceps/hamstrings, squat and counter movement jump (SJ and CMJ) and discomfort evaluations (Quadriceps, Hamstrings, Gluteus and Calf).

Results: MIVC showed an improvement at 48 hours for the quadriceps in the CWI and WBC groups but with no alterations on MIVC of the hamstrings. SJ also recorded significant ($p < 0.05$) improvements at 24 and 48 hours at the Cryotherapy groups versus control, while CMJ did not show any differences. Fatigue perception did not present any significant differences except for the Quadriceps, where CWI and WBC reported lower discomfort at 48 hours.

Conclusions: SJ at 24h and 48h, MIVC of the Quadriceps at 48h and Discomfort of the Quadriceps at 48h showed better performance recovery with either Cryotherapy rather than PR. Other variables show no differences among groups. No differences between CWI and WBC were shown at any time point.

Key Words: CRYOTHERAPY; COLD WATER IMMERSION; WHOLE BODY CRYOTHERAPY; ATHLETES; FATIGUE; RECOVERY;

Resumo

Introdução: Apesar de a Crioterapia estar estabelecida como benéfica na atenuação da inflamação e do dano tecidual, ainda é vista com controvérsia no meio desportivo. Alguns autores mostram a Crioterapia como potencialmente benéfica para a recuperação após exercício intensivo, porém mais pesquisa é necessária.

Objetivos: Este estudo examinou os eventuais benefícios fisiológicos e psicológicos de Imersão em Água Fria e Crioterapia de Corpo Inteiro na atenuação de fadiga induzida pelo exercício em atletas.

Material e Métodos: Quarenta atletas (40) foram arbitrariamente distribuídos em três grupos, cada um com uma estratégia de recuperação distinta. Os atletas realizaram um protocolo de fadiga de prensa de pernas com 300 repetições a 80% do peso corporal, respeitando um rácio de trabalho 3:1 de contrações excêntricas e concêntricas. Seguidamente, cada grupo realizou o método de recuperação correspondente: Imersão em Água Fria (10ºC a 10 minutos), Crioterapia de Corpo Inteiro (-190ºC a 2 minutos) e Recuperação Passiva (Controlo).Os seguintes parâmetros de *performance* foram avaliados: Contração Isométrica Voluntária Máxima (CIVM) dos quadríceps e isquiotibiais, Salto *Squat* e com Contramovimento e Avaliações de Desconforto Muscular (quadríceps, isquiotibiais, gémeos e glúteos).

Resultados: A CIVM registou uma melhoria às 48 h para o quadríceps em ambos os grupos de Crioterapia, porém sem alterações da CIVM dos isquiotibiais. O salto em *Squat* demonstrou melhorias significativamente pronunciadas às 24 h e 48 h nos grupos de Crioterapia em comparação com o Grupo de Controlo. Já o salto com Contramovimento não evidenciou nenhuma diferença significativa em nenhum dos períodos temporais considerados. Perceção de fadiga apenas apresentou diferenças nos quadríceps às 48 h. Os restantes músculos e períodos de tempo não exibiram diferenças significativas.

Conclusões: Salto em *Squat* às 24 h e 48h, CIVM às 48 h e Perceção de Fadiga dos quadríceps às 48h apresentou melhor recuperação da *performance* com Crioterapia comparado com Recuperação Passiva. Outras variáveis (Salto com Contramovimento e CIVM dos isquiotibiais) não revelaram diferenças significativas em nenhum momento. Imersão em Água Fria e Crioterapia de Corpo Inteiro afetaram a recuperação de modo similar.

Palavras-Chave: CRIOTERAPIA; IMERSÃO EM ÁGUA FRIA; CRIOTERAPIA DE CORPO INTEIRO; ATLETAS; FADIGA; RECUPERAÇÃO

Résumé

Introduction: Bien que la Cryothérapie soit établie comme bénéfique pour atténuer l'inflammation et les dommages aux tissus, elle fait toujours l'objet de controverse dans le sport. Certains auteurs montrent la Cryothérapie comme potentiellement bénéfique pour la récupération après un exercice intensif, mais plus de recherches seront utiles.

Objectifs: Cette étude a examiné les possibles avantages physiologiques et psychologiques de l'Immersion en Eau Froide (IEF) et Cryothérapie Corps Entier (CCE) dans l'atténuation de la fatigue induite par l'exercice chez les athlètes.

Matériel et Méthodes : Quarante (40) athlètes ont été arbitrairement divisés en trois groupes, chacun avec une stratégie de récupération distincte. Les athlètes ont effectué un protocole de fatigue de presse de jambes de 300 répétitions à 80% du poids du corporel, avec un rapport de travail 3:1 de contractions excentriques et concentriques. Ensuite, chaque groupe a effectué la méthode correspondante de récupération: Immersion en Eau Froide (10°C à 10 minutes), Cryothérapie Corps Entier (-190ºC à 2 minutes) et Récupération Passive (Groupe de Contrôle). Les paramètres de performance suivants ont été évalués: Contraction Maximale Volontaire Isométrique (CMVI) du quadriceps et des ischio-jambiers, Sauts Verticaux (*Squat Jump* et *Countermovement Jump*) et Évaluation de l'Inconfort Musculaire (quadriceps, ischio-jambiers, mollets et fessiers).

Résultats: CMVI a amélioré à 48 h pour les quadriceps dans les deux groupes de Cryothérapie, mais sans altérations de la CMVI des ischio-jambiers. Le saut Squat a apporté une amélioration significative à 24 h et 48 h dans les groupes de Cryothérapie par rapport au Groupe de Contrôle. Cependant le saut de *countermovement* n'a pas montré de différence significative dans chaque période considérée. La perception de fatigue a produit seulement des différences dans les quadriceps à 48 h. Les muscles et les autres périodes de temps ne présentent pas de différences significatives.

Conclusions: *Squat Jump* à 24 h et 48 h, Contraction Maximale Volontaire Isométrique (CMVI) du quadriceps à 48 h et perception de la fatigue du quadriceps à 48h ont montré une meilleure performance de récupération par Cryothérapie par rapport à la récupération passive. D'autres variables (saut de *countermovement* et CMVI des ischio-jambiers) n’ont pas montré de différences significatives à aucun moment. Immersion en eau froide et Cryothérapie Corps Entier ont affecté la récupération de la même façon.

Mots-clés: CRYOTHERAPIE ; IMMERSION EN EAU FROIDE ; CRYOTHERAPIE CORPS ENTIER ; ATHLETES ; FATIGUE ; RÉCUPÉRATION

List of Abbreviations

Cº - Degrees Celsius

CMJ – Counter Movement Jump

CWI – Cold Water Immersion

CWT – Contrast Water Therapy

DOMS – Delayed Onset Muscle Soreness

HIT – High Intensity Training

HWI – Hot Water Immersion

MIVC – Maximum Isometric Voluntary Contraction

N/m – Newton/meter

PR – Passive Recovery

RM – Repetition Maximum

SJ – Squat Jump

SSC – Stretch Shortening Cycle

TWI - Thermoneutral Water Immersion

WBC – Whole Body Cryotherapy

1. Introduction

Athletes may suffer from muscle soreness as a direct result from intense practices or competition. Muscle soreness is a phenomenon which people who interact with sport have experienced either themselves or by hearing reports from others. It usually happens as a result of an intense training session or as a result of an unaccustomed exercise. It happens relatively often and should be faced as something normal instead of injury. This delayed onset muscle soreness (DOMS) commonly peaks between 24 and 72 hours after exercise but may present at as early at 12 hours. It is characterized by muscle shortening, increased passive stiffness, swelling, decreases in strength and power, localized soreness and altered proprioception (Proske & Morgan, 2001).

Ferreira et al. (2014) refers that short-term neuromuscular performance impairment may result from several factors, such as: decreased muscle pH (Cairns, 2006; Sahlin, 1992; Sahlin, 1986; Ferreira et al., 2015) , depletion of phosphocreatine (Casey, Constantin-Teodosiu, Howell, Hultman & Greenhaff, 1996; Sahlin, 1992; Sahlin, 1998; Ferreira et al., 2015) , ATP (Casey et al., 1996; Dutka & Lamb, 2004; Ferreira et al., 2015) and muscle glycogen stores (Balsom, Gaitanos, Soderlund & Ekblom, 1999 ; Ferreira et al., 2015), metabolic products accumulation from muscle contractions (Dutka & Lamb, 2004; Moopanar & Allen, 2005, Sahlin, 1998; Ferreira et al.,2015) or reduction in brain signals to muscle fibers (Bishop, Jones & Woods, 2008; St Clair Gibson, Lambert & Noakes, 2001; Ferreira et al., 2015) all of which contribute negatively for performance.

Regardless, DOMS should not be classified as an injury, as resting or lowering training volume will definitely facilitate recovery. Obviously, this isn't always an option. If one is looking for high performance, abstaining from training or reducing physical load might not always be the correct solution. As such, techniques to fasten recovery are very sought out by trainers.

Active recovery, Massages, Thermal Contrast Therapy, Hydrotherapy (not necessarily cold water), Stretching, Hyperbolic oxygen therapy, Anti-inflammatory supplementation, Electro stimulation, Compression clothes and, Cryotherapy, are some of examples of recovery techniques that have recently been shown interest by the sports community. Specifically, Cryotherapy is a recovery mode defined as a method of lowering body temperature to certain levels in defined period of time. It supposedly acts like an accelerator of muscular and metabolic regeneration by aiding the body natural inflammatory response.

Post-exercise cold water immersion (a type of Cryotherapy) is widely used to treat acute traumatic injury with much success and may be appropriate as a recovery strategy. Despite this, while some studies have been made on this topic, there is some controversy regarding the effectiveness of Cryotherapy as a tool for post training/ competition recovery. Bleakley et al. (2012) on his review regarding cold water immersion studies, conveyed data that cold-water immersion might reduce delayed onset muscle soreness, strength decline, neuromuscular fatigue and the presence of certain fatigue metabolites when compared with passive recovery.

Another recent trend on recovery strategy is Whole Body Cryotherapy. This is a variation of Cryotherapy which is relatively new and consists of low temperature exposure (-110º to -190º) in a very little time period (3 minutes is the maximum reported). This particular form of Cryotherapy has not been explored too deeply, with only a handful of studies on this subject. Though, a study where CWI and WBC are compared with a controlled PR intervention seemed like a promising study. With this in mind, this study analyzed the recovery process after strenuous exercise through the evaluation of maximum voluntary contraction, vertical jump and subjective discomfort test comparing CWI, WBC and passive recovery.

2. Literature Revision

The fundamental purpose behind this study was to determinate whether CWI (Cold water immersion), WBC (Whole body Cryotherapy) or PR (Passive rest) have any significant effect on recovery from exercise induced muscle damage. Data was gathered from numerous distinct sources mostly found with google scholar such as: *European Journal of Applied Physiology, Journal of Athletics Training, Journal of Sport Science, British Journal of Sport medicine, Journal of Sports Science and Medicine, Journal of Athletic Training, International Journal of Sports Medicine,* etc. Keywords used were: Cryotherapy, Hydrotherapy, CWI, WBC, Recovery, Strength, Power, Neuromuscular, Squat Jump, CMJ, DOMS, Discomfort, Fatigue and Athletes.

The following literature revision conveys information on:

- Different types of muscle contractions and how they relate with force and length, namely concentric, eccentric, isometric and isokinetic contractions, as well as the mechanics of the shorten and lengthen cycle;

- Muscle damage and some of its respective indirect markers, such as maximum isometric voluntary contraction (MIVC), Squat and Counter Movement Jumps and pain, fatigue and discomfort;

- Cryotherapy, more specifically on Cold Water Immersion and Whole Body Cryotherapy methods. Also, the contraindications, timing, time and temperature suggestions of each method based on existing studies.

It's important we understand the mechanisms behind what we intend to study, as well as the background of the variables we intend to measure, in order to design a successful study. This review serves as backbone of the study, it explains why the study protocol design is as it is, the fundamentals behind each test and gives some insight on previous studies in the area.

2.1) Muscle actions

The performance of sports and all physical exercise is the result of a coordinated activation of the appropriate skeletal muscles. These muscles, acting through the lever systems of the body skeleton, provide the forces and the power that can be translated into skilled movement (Komi, 1993). A muscle is contractile tissue that when stimulated generates tension accordingly, such phenomenon is labeled a muscle contraction.

According to Bartlett (1997), the tension developed in a muscle depends on numerous factors:

- The number of fibers recruited and their firing (or stimulation) rate and synchrony;
- The relative size of the muscle, the tension being proportional to the physiological cross-sectional area of the muscle;
- The temperature of the muscle and muscle fatigue;
- The pre-stretch of the muscle a muscle that develops tension after being stretched (such as the shortening-length cycle);
- The mechanical properties of the muscle, as expressed by the length–tension, force–velocity and tension–time relationships;

For striated muscles, all contractions happen as a result of the voluntary efforts originating from the brain. It sends signals in the form of spike trains, through the nervous system to the motor neurons which enervate several muscle fibers. Contractions can often differ from one another. Figure 1 displays the types of contraction that exist and how they correlate with movement and length.

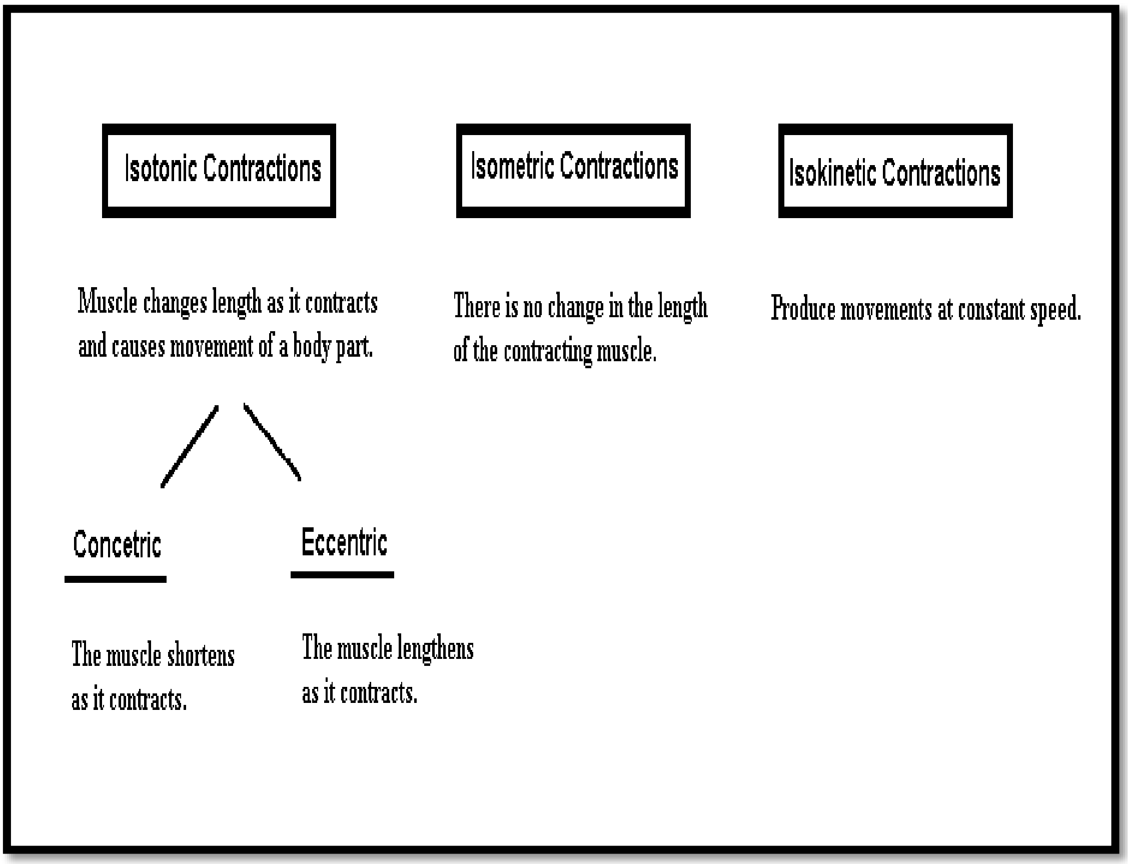

Figure 1 – Diagram explaining the different types of contractions.

Dissimilar types of contractions have many differences between them, such as being able to produce more force or being more susceptible to damage (Chapman, Newton, Sacco & Nosaka, 2006). A focus on concentric and eccentric, isokinetic and isometric contractions, as well as the mechanics of the stretch-shortening cycle was given. Each of these were basis for the protocols which this investigation is based on. Concentric and Eccentric contractions were the basis for squat jump evaluation and the fatigue protocol; Isometric contraction as a means to assess the quadriceps and hamstrings maximal strength; Isokinetic equipment which allowed for evaluation of maximal strength under the same conditions and the SSC as basis for the counter movement jump test.

2.1.1) Concentric and Eccentric Contractions

In Eccentric contractions, the muscle develops and lengthens as it contracts as opposed to shortening, as one would find in a concentric contraction. They are characterized by the ability to achieve high muscle forces, an enhancement of the tissue damage (that is associated with muscle soreness) and perhaps require unique control strategies by the central nervous system (Donatelli & Wooden, 1989).

During a concentric contraction exercise, muscle fibers would slide across each other pulling the Z-lines together. During an eccentric exercise contraction, the filaments slide past each other the opposite way. These contractions are able to generate more force while still providing more energy efficiency per unit of torque (Howatson & Van Someren, 2008).The faster a muscle shortens during a concentric contraction, the less the maximum force it can exert. Controversially, the maximum force that a muscle can achieve during a voluntary eccentric contraction is largely unaffected by changes in the speed of lengthening, at least beyond an initial limit. Eccentric contractions also assist in keeping motions smooth and can also slow rapid movements.

Strength training involving both eccentric and concentric contractions has been shown to improve muscular strength more than training exclusively using concentric contractions (Colliander & Tesch, 1990), however muscle damage induced from exercise appears to be greater during eccentric contractions (Nikolaidis et al.,2012).

Research on this matter suggests that less muscle's fibers be recruited during a maximal eccentric contraction, with fast twitch fibers recruited in preference to slow twitch ones, and, seem to produce more strength per fiber than isometric and concentric contractions alike. The increased probability of injury during lengthening contractions arises in part from the greater average forces developed by fully activated muscles during lengthening compared with shortening or isometric contractions (Bartlett, 1997).

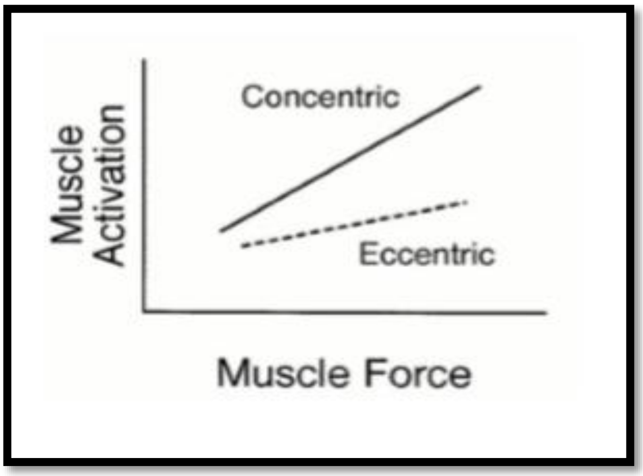

Figure 2 - Difference between concentric and eccentric contractions in required muscle activation (electromyography) to achieve a given muscle force (Source: Enoka, 1996).

The degree of muscle injury rises with an increasing number of eccentric contractions on top of the degree of stretch happening (Morgan and Allen, 1999). For that reason eccentric contractions have been used in a several studies which aim to induce muscle damage and are ideal for implementation on designs of investigations which utilize fatigue protocols.

2.1.2) Isokinetic Devices

The concept first arose with authors as Thistle, Hislop, Moffroid and Lowman (1966), Hislop & Perrine (1967), and Moffroid, Whipple, Hofkosh, Lowman and Thirtle (1969), and has been a valuable tool for assessing muscular function and pathology's.

Isokinetic dynamometers are passive devices which resist applied forces and control the speed of exercise at a predetermined rate. It makes sure the velocity of movement is maintained constant and the resistance is equal to the muscular forces applied throughout the range of movement (Baltzopoulos & Brodie 1989).

According to Pincivero, Lephart & Karunakara (1996) some advantages of isokinetic devices is that they permit the isolation of muscle groups, provides accommodation to resistance to maximum exercise throughout the entire range of motion and presents quantifiable data on peak torque, work and power. Other parameters like angle-specific torque, torque acceleration energy, and various endurance indexes, can also be measured by these devices, be made isometrically at various angular positions and isokinetically (concentrically or eccentrically) with a large scale of angular speeds, making it an ideal tool for rehabilitation and investigation.

2.1.3) Isometric Contractions

Muscular exercise may be of dynamic (concentric, eccentric, isokinetic) or static (isometric) nature. Isometric muscle contractions are those that have a constant length or static contraction with a zero velocity of shortening (Noreau & Vachon, 1998).They differ from isokinetic contractions, because, while both have constant speed, on an isometric contraction, the speed is null. It has an important role in the early phases of rehabilitation, when movement is limited or significant arcs of pain are present. They have also been used, together with isokinetic dynamometers, in a number of papers studying fatigue and muscular exhaustion, being accepted as a viable tool to measure maximum isometric strength, as the lack of movement and fixed angle makes it easy to compare performances.
Despite this, it's not a very good indicator for specific movements or performance (Perrin & Costill, 1993).

2.1.4) Stretch-Shortening Cycle (SSC)

The classifications used above, while accurate, cannot however be used to describe the natural flow of a muscle action. The muscle function is difficult to assess from isolated forms of isometric, isokinetic, concentric or eccentric actions, since in real life, exercise seldom involves a pure form of these types of isolated muscle actions (Komi, 1993). The true definition of eccentric action indicates that the muscles must be active during stretch. This combination of eccentric and concentric actions forms a natural type of muscle function called the stretch–shortening cycle or SSC (Komi 1993). SSC muscle function has a well-recognized characteristic: enhancement of performance during the final phase (concentric action) when compared to the isolated concentric action (Komi, 1993). An example is a quick countermovement before a verdict jump occurs. This allows the quadriceps to be stretched eccentrically so that the following concentric contraction can be stronger (thus jumping higher).

It has been demonstrated that the natural SSC-type locomotion loads the neuromuscular system in a more complex way than any isolated forms of muscle actions (Komi, 1993). However, the immediate post exercise changes in a SSC intensive exercise are naturally related primarily to metabolic disturbances, whereas the delayed recovery are associated with the well-known inflammatory processes related to muscle damage (Faulkner, Brooks & Opiteck, 1993).

If a plyometric (stretch-shortening cycle) muscle action is performed with high volume and intensity, it will often cause the delayed onset of muscle soreness (DOMS) (Hunter and Faulkner, 1997; Chatzinikolaou et al., 2010; as cited in Sarabon, Panjan, Rosker & Fonda, 2013). It might make sense to make use of methods who make use of this system when trying to induce muscular damage. Likewise a number of studies have observed that exercise induced muscle damage causes a prolonged reduction in vertical jump height (Byrne and Eston, 2002; Horita et al., 1999; as cited in Sarabon et al. 2013) who actively relies on this cycle.

Those who intended to evaluate how exercise induced muscle damage affects the contractile and elastic properties of the muscle, may find a logical step to implement a jump protocol.

2.2) Markers of exercise induced muscle damage

Understanding what a task demands, on both metabolically and mechanically levels is of extreme importance in sports context. It allows for careful planning, preparation and to make clear objectives, all while considering the benefits and disadvantages of a specific task. Because the muscle produces force, any substantial shift in the normal pattern that the muscle uses may result in muscle soreness, if either the nature or the magnitude of the force production changes significantly (Lindstedt, LaStayo & Reich, 2001). Thus, fatigue from exercise can have contributions from either metabolic imbalance or mechanic stress injury.

Mechanical stress imposed on active skeletal muscle during exercise that includes high force contractions, such as plyometric or resistance training may cause direct physical disruption of the sarcolemma, sarcomeres, excitation/contraction coupling system and connective tissue associated with the muscle (Armstrong, Ogilvie and Schwane, 1983). Correspondingly, on a metabolic level, stressed muscle fibers may have an increased energy demand as they restore ion gradients, repair structural impairment and repair energy stores (Hom, Vasquez and Pozos, 2004). As muscle damage induced by exercise is such a common phenomenon, the mechanisms responsible for damage, recovery, and prevention have received a great deal of attention over the years. The methods used to effectively analyze muscle damage induced by exercise may be executed by a direct or indirect method.

Direct methods mostly consist of muscle biopsies analysis or imaging techniques such magnetic resonances (Friden, 1981). Some problems arise with using muscle biopsies. Small samples are used to estimate damage over an entire muscle which might lead to false data. Also, the invasive nature of a biopsies makes it a difficult method to reproduce on humans. Therefore, an over- or under-estimation of the extent of damage can occur as muscle damage tends not to be evenly distributed throughout a muscle (Clarkson and Hubal, 2002).
As for imaging techniques, they are able to measure edema formation in whole muscles and though non-invasive, it remains uncertain what the fluctuations in images indicate (Clarkson and Hubal, 2002).

Indirect methods are more diverse and are used more commonly. They are mostly noninvasive and usually more practical to use. They can consist of several tests such as swelling measures, differences in range of motion, perception of pain or discomfort, temperature study, neuromuscular activities (sprint or vertical and horizontal jump height/distances), evaluations for maximal strength, power or resistance, blood analyzes for biochemical fatigue markers (Creatine Kinase, Cortisol, …), etc.

2.2.1) Maximum Strength

Maximum strength is represented by the highest amount of force that the neuromuscular system is able to produce through a maximum voluntary contraction, which may be of dynamic or static characteristics (Weineck, Carvalho & Barbanti, 1999; Bulatova & Platonov, 1998). Generally speaking, maximal torque, either voluntary or electrically evoked, is higher during isometric contractions compared with concentric contractions, with the concentric torque declining with the increasing of the angular velocity (Babault et al., 2006).

MIVC (Maximum Isometric Voluntary Contraction) has been used in a number of studies to assess the maximal strength of participants and is a valid marker for exercise induced muscle damage (Eston & Peters, 1999; Bailey et al., 2007; Sellwood, Brukner, Williams, Nicol & Hinman, 2007; Goodal & Howatson, 2008; Hausswirth et al., 2011). The manifestation of strength from a MIVC differs among concentric, eccentric, isokinetic and isometric exercises, therefore, strength is the result of an assessment performed under a single set of conditions (Linnamo, Bottas & Komi 2000). A variable number of values for muscle strength may be obtained either for an isolated muscle preparation or for a human movement, as related to the type of action, the velocity of the action, and the length of the muscles when the measurement is accomplished (Komi, 1993). Because of the number of variables or conditions involved, strength of a muscle or muscle group must be defined as the maximal force generated at a specified or determined velocity and angle (Knuttgen & Kraemer 1987).

Some variables such as angle and velocity may be properly controlled using the aid of an isokinetic dynamometer, which makes it viable for comparisons between participants isolated under the same set of conditions.

2.2.2) Explosive Power and Neuromuscular Function

It's known that the better an athlete's qualifications, the greater the role of explosive and neuromuscular development in the achievement of high-level performance. Vertical and horizontal jumps are used fairly regularly to evaluate explosive and neuromuscular function. As the neuromuscular performance qualities of muscles have been shown to be similar in vertical jumps and running, its performance may be highly relevant for measuring various parameters important in sport where running is a principal constituent (Cormack, Newton, McGuigan & Doyle, 2008).

According to Bailey et al. (2007), squat jumps are a golden measure to evaluate non direct muscle damage and the general functional ability of a person. For counter movement jump, Cormack et al. (2008) claim that after a game of Australian Football, countermovement jump flight-time: height and contraction time ratio has been established as the most sensitive and useful variable for the assessment of neuromuscular fatigue.

Both jumps are important and necessary for human performance and a vital skill for certain sports (such as basketball or volleyball). A number of studies have observed that shortly after HIT a prolonged reduction in vertical jump height occurs (Byrne and Eston, 2002; Horita et al., 1999; as cited in Sarabon et al. 2013 making them viable to add on experimental protocols which aim to evaluate explosive and neuromuscular condition under fatigue conditions.

2.2.3) Pain, Discomfort and Soreness

One's restriction or lack of aptitude to fulfill a task among what can be considered normal for an individual, may be considered as a limitation (Cheung, Hume & Maxwel, 2003). Such line of thought leads to consider, pain, discomfort, fatigue and soreness as valid handicaps and valuable markers for exercise induced muscle damage.

According to Faulkner et al. (1993), the first publication about exercise-induced muscle damage was in 1902 by Hough. Hough's participants performed rhythmical contractions of the finger flexor muscles till exhaustion. Hough noted that the muscles became sore, and that the soreness was not reported at the time of the contractions, but developed 8 to 10 hours later, being the most severe 48 to 60 hours afterward. It has since continued a heavily researched topic. Studies established that, for human beings, the delayed soreness in exercised skeletal muscles was more likely to occur and to be more severe after exercise consisting of predominantly lengthening (eccentric) contractions than after exercise consisting of either isometric or shortening (concentric) contraction (Faulkner et al., 1993). However, generally, muscle injury can be induced in static (isometric) or dynamic (concentric, eccentric, isokinetic) muscle contractions.

Its general consensus that exhaustive or unaccustomed intense exercise can cause muscle damage, which results in muscle soreness, temporary decrease in muscle force, edema, inflammation and an increase of intra-muscular proteins in blood (Howatson & Van Someren, 2008). This has been recognized as Delayed onset muscle soreness (DOMS). Any type of activity that places unaccustomed loads on muscle may lead to DOMS, which is one of the most undesirable consequences of exercise-induced muscle damage, especially in practical athletic terms. It has a fundamental negative impact on muscle function, namely the decrease in muscle force-generating capacity (McGinley, Shafat & Donnelly 2009). This muscular impairment may be transitory, lasting minutes, hours, or several days following intensive training or competition (Barnett, 2006). Therefore, exercise induced muscle damage easily effects a maximum voluntary contraction (MIVC), encompassing both maximal force and the maximal rate of force development (Warren et al., 1999; Eston et al., 2003; Strojnik and Komi, 1998; Vila-Chã et al., 2012; as cited in Sarabon et al. 2012), suggesting MIVC as possible tool to measure fatigue.

It's been documented that eccentric contractions cause a fair amount of damage to the muscular fibers (Sesto, Chourasia, Block & Radwin, 2008) and this damage is greater in eccentric than in concentric or isometric contractions, thus contributing more for DOMS (Friden & Lieber, 1998). It is believed that this is due to the increased tension as the muscle lengthens which results in a higher load distributed amongst the same number of fibers (Clarkson & Hubal, 2002).

Within a myofibril, some sarcomeres are stronger than others and it is hypothesized that when the myofibrils are stretched during an eccentric contraction, the weaker sarcomeres absorb more of the stretch (Morgan and Allen, 1999, Proske and Allen, 2005, Proske and Morgan, 2001). Consequently, these sarcomeres become progressively weaker and when they reach their yield point, they lengthen uncontrollably and rapidly to the point of little or no overlap (Clarkson and Sayers, 1999; Proske and Morgan, 2001) eventually disrupting. This disruption can lead to damage of nearby elements of the muscle such as the sarcoplasmic reticulum, transverse tubules or muscle membrane (Proske and Morgan, 2001). This can lead to a loss of membrane integrity consequently allowing intramuscular proteins to leak out (Clarkson and Sayers, 1999). A schematic of the events leading to muscle damage is represented at Figure 3, courtesy of *The Journal of Physiology*.

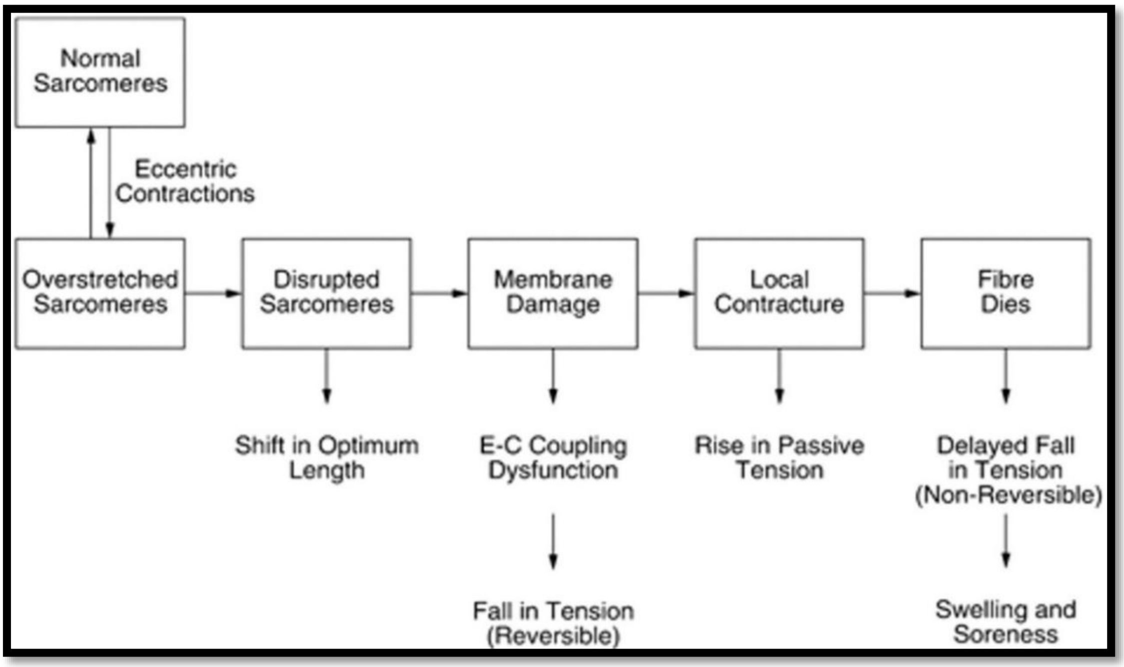

Figure 3- Postulated series of events leading to muscle damage from eccentric exercise (Source: The Journal of Physiology, Volume 537, Issue 2, pages 333–345, December 2001).

Considering how eccentric movements correlate with DOMS, it's no surprise it has been used as a marker for exercise induced muscle damage. DOMS has been used in a number of studies using recovery methods, in an attempt to diminish its symptoms (HOWATSON, GOODALL & VAN SOMEREN, 2009), some of which include, Cryotherapy.

2.3) Cryotherapy

Post-exercise Cryotherapy is widely used to treat acute traumatic injuries and may be appropriate as a recovery strategy after training and competition that cause some level of traumatic injury (Swenson, Sward, & Karlsson, 1996; as cited in Ascensão, Leite, Rebelo, Magalhães S. and Magalhães J., 2011).

Some studies have shown that it may also be appropriate as a recovery strategy after training or competition where players report acute soft-tissue injury as well as contraction-induced muscle disarrangements that typically result in delayed-onset muscle damage (Ascensão et al. 2011). Its purposed effects include analgesia, localized vasoconstriction, decreased rate of muscle metabolism, reduced fluid diffusion and vascular permeability, reduced edema formation and decreasing acute inflammation responses from muscle damage (Bleakley, Bieuzen, Davison and Costello, 2014). Among utilized methods are wet towels, ice bags, ice massages, cold water immersions, cold whirlpool, etc. (Knight 2000). A relatively new modality of Cryotherapy is whole-body Cryotherapy (WBC), which consists of brief exposure (2–3 min) to extremely cold air (−100ºC to −195°C) in a temperature-controlled chamber or cryocabin (Banfi, Lombardi, Colombini and Melegati 2010; Hausswirth et al., 2011; Fonda and Sarabon, 2013; as cited in Ferreira, et al. 2014).

This study focuses on CWI (cold water immersion) and WBC (whole body Cryotherapy) Cryotherapy variations. These techniques are typically performed within 30 min post intense exercise (albeit some exceptions exist), with varying times and temperatures. It's to be noted that, although it's an important component in the established management of acute musculoskeletal injuries and while it has, to some extent, been used in training, there is some conflict about its effects. This is largely due to a high variability in methodology used to study Cryotherapy as a recovery modality (White**,** Rhind & Wells, 2014).

Several authors have investigated Cryotherapy recovery proprieties by evaluating most pain parameters, tenderness, isometric strength, swelling, angle of force, jump heights or distances, plasma indicators and perception of pain/discomfort. To the present date, the overall state of the art is somewhat equivocal with regards to the efficacy of Cryotherapy as a recovery tool. Although investigations have shown some positive effects, there are still many inconsistencies between most studies, with no consensus in sight.

2.3.1) Cold water immersion (CWI)

Many strategies are used with the intention of preventing or minimizing delayed onset muscle soreness and fatigue after exercise (Bleakley et al. 2012). Cold water immersion is considered one of the most used recovery methods (Barney 2006, as cited in White et al. 2014) and it has been used extensively on the field of sports medicine with a rising trend in high performance training. CWI consists on using ice blocks in water filled containers in which the subject will immerge the selected body parts. These participants are usually passive during immersion in still water (Versey, Halson & Dawson, 2013). When a body is submerged, the water will exert a force called hydrostatic pressure, which may cause fluid to roam from the extremities to the body center. When external pressure on the body increases, gas and fluid substances are displaced to lower pressure areas (Bove, 2002; Farhi & Linnarsson, 1977; Lollgen et al., 1981 as cited in Wilcock, 2005) therefore, a person standing in water experiences compression on the body acting inwards and upwards (Wilcock, Cronin & Hing, 2006). This fluid supposedly increases substrate translocation, heart rate and increase the body's ability to transfer substrates (Wilcock et al., 2006). These increased central blood and extracellular fluid volumes via intracellular-intravascular osmotic gradients, and decreased peripheral resistance, contributes to increased removal of metabolic byproducts with the potential for enhancing recovery from exercise (Wilcock et al., 2006; as cited in Ascensão et al., 2011). However it doesn't seem likely that the eventual recovery benefits are affected by hydrostatic pressure; it's more likely due to the water temperature (Ascensão et al., 2011).

In the current state of the art, there's a fair amount of studies which have used cold water immersion as a recovery means and tried to assess its importance in practical athletic terms. Temperatures and Time vary between studies, so one must carefully review which methodology has been used and not make hasty comparisons.

Kuligowski, Lephart, Giannantonio & Blanc (1998), examined fifty-six volunteer (n=56) males and females to determine the efficacy of warm whirlpool, cold whirlpool, and contrast therapy in the treatment of delayed-onset muscle soreness (DOMS). These participants performed eccentric contractions of the elbow flexors as a fatigue protocol and received 4 treatments: immediately post exercise and 24, 48, and 72 hours post exercise. Treatments consisted of 24-minute treatments with warm whirlpool, cold whirlpool, contrast therapy, or no treatment. While not a specifically a passive CWI, based on the results of this study, Kuligowski et al. concluded that the application of cold through the use of cold whirlpool therapy is was effective and the best of the 3 treatment for DOMS.

Eston & Peters (1999) examined fifteen (15) female student volunteers (with mean ages 22.0 ± 2.0, non-trained) and their responses after a bout of eccentric exercise (eight sets of reciprocal contractions at 0.58 rads-1) on the elbow flexors of the dominant arm (in order to induce DOMS). The participants were allocated at random to either a Cryotherapy treatment group or a control group. These participants conducted 7 sessions of CWI in 12 hour increments post fatigue protocol (during 3 days) for 15 minutes at 15ºC. The findings provided support for Cryotherapy usage on the extent it helped increase the range of motion after eccentric exercise when compared with control conditions. It appears that this form of Cryotherapy decreases the degree of shortening of the muscle or the connective tissue after eccentric exercise but evidence was also presented to indicate a possible reduction in damage to the muscle tissue. However, Eston & Peters (1999) claim that despite the apparent effects of Cryotherapy on exercise-induced muscle damage, it does not appear to alter the normal temporal pattern of tenderness, swelling and strength loss.

Sellwood et al. (2007) studied 40 untrained participants who performed an eccentric loading protocol with their non-dominant leg. Participants were randomized to three 1-min immersions in either ice water (5 ± 1˚C) or tepid water (24˚C). According to the authors, the use of this intervention is unnecessary. No significant differences were observed between groups with regard to changes in most pain parameters, tenderness, isometric strength, swelling, hop-for-distance or serum CK over time given. It was concluded that ice-water immersion is ineffectual to prevent symptoms of muscle damage after eccentric exercise in young, relatively untrained individuals. Considering that trained athletes are relatively well protected against DOMS, the authors feel that ice-water immersion is likely to offer them even less benefit for the minimal soreness they may experience after eccentric exercise.

Bailey et al. (2007) studied the effects of CWI on indices of muscle damage on twenty active males (20). An acute CWI session (10ºC for 10 minutes) was applied right after an extensive intermittent exercise bout (shuttle run). The authors reported significantly reduced pain sensation at 1h, 24h and 48h markers after a fatigue protocol. Furthermore, MVC was improved in CWI at 24h and 48h versus control circumstances. Vertical Jump and Sprint was unaffected by cold water immersion.

Vaile, Halson, Gill, & Dawson (2008) studied the effects of three hydrotherapy interventions on the physiological and functional symptoms of delayed onset muscle soreness (DOMS). Vaile et al. (2008) examined strength trained males (n= 38) as they completed two experimental trials separated by 8 months in a randomized crossover design; one trial involved passive recovery (PR, control), the other a hydrotherapy protocol for 72 hours post-exercise; either: cold water immersion (CWI), hot water immersion (HWI) or contrast water therapy (CWT). CWI participants immersed their entire body (excluding head and neck) in 15°C water for 14 min during multiple sessions. The DOMS-inducing exercise protocol consisted of 5x10eccentric bi-lateral leg press contractions with a load of120% of one repetition maximum (1 – Concentric RM) followed by 2x10 at a load of 100% (1-RM). Change in peak power and maximum strength performance (%change from baseline) when compared with control conditions, was significantly less at 48 and 72 hours post-exercise following CWI compared with PR. CWI was effective in reducing swelling, but the results this investigation presents do not indicate an altered perception of pain or discomfort compared to the PR group. The authors explain that while participants might have experienced an acute analgesic effect immediately post-CWI, such effect had diminished 24 h post-recovery.

Montgomery et al. (2008) studied effectiveness of multiple CWI sessions (5 x1 min at 11°C) versus carbohydrate and stretching versus full compression garments. Twenty nine (29) male players (mean age 19.1 ± 2.1 years) completed a three (3) day basketball tournament meant as a specific sport fatigue protocol. The authors concluded that CWI effectively reduced perceptions of fatigue across the tournament, as well as sprint and vertical jump (SJ) performances.

Goodall & Howatson (2008) studied eighteen males (18) and the efficacy of repeated cold water immersions (CWI) in the recovery of EIMD. The damaging bout was compromised of 100 drop jumps. CWI was randomly conducted by one group at 15ºC for 12 minutes, immediately after the fatigue and after in 24 hour increments. The remaining participants were allocated to the control group who recovered passively. The variable observed were: Maximal voluntary contraction (MVC) of the knee extensors, creatine kinase activity (CK), muscle soreness (DOMS), range of motion (ROM) and limb girth. The final results showed that CWI was ineffective in aiding recovery, as damage from exercise was evident and still no noticeable differences existed between groups in any variables.

Ingram, Dawson, Goodman, Wallman & Beilby (2008) also observed significantly lower muscle soreness ratings for CWI, than in control conditions on eleven (11) trained male athletes . Additionally, only after CWI (Labelled as COLD by Ingram et al.) were best sprint and total sprint times at 48h similar to base line values. Further, leg strength recorded at 48h post-exercise was similar to baseline values for leg extension and flexion after CWI, whereas significant decrements were recorded for control conditions. Ingram also found no significant differences between recovery conditions for markers of muscle damage and inflammation between groups that used CWI and those who hadn't.

Kinugasa & Kilding (2009) compared post-match recovery strategies in youth soccer players. These included cold water immersion (CWI), contrast water therapy (CWT) and passive recovery (PR). These investigators found no substantial benefit for implementing a CWI recovery modality on physical muscular performance compared with contrast water immersion or passive recovery, although it did result in better perceived recovery compared with PR.

The authors Jakeman, Macrae & Eston (2009) claim that the effectiveness of a single bout of cold-water immersion as a treatment and prevention strategy for the symptoms of DOMS after intensive exercise is very doubtful.

On this study, the effectiveness of a single bout of cold-water immersion on recovery from exercise-induced muscle damage was measured. Eighteen physically active female volunteers (age 19.9 ± 0.97 years), height 1.66 (± 0.05 m), mass 63.7 (± 10 kg), completed 10 sets of 10 counter-movement jumps to induce muscle damage. The participants were randomly allocated to a control or treatment group. The treatment group was given a single 10-min bout of lower limb cold-water immersion therapy at 10ºC immediately following damage-inducing exercise. A single bout of cold-water immersion therapy had no significant effects on a variety of markers of DOMS and it has been concluded that a single bout of cold-water immersion therapy at 10ºC for 10 minutes is not effective in providing an enhanced recovery rate for individuals suffering from DOMS.

This line of thought is somewhat maintained in King's & Duffield (2009) study, which says that despite the implementation of recovery methods such as CWI, there is minimal evidence to support the effectiveness of these strategies in aiding performance in bouts separated by 24 hours of recovery. However, King's & Duffield (2009) also found similar results as Kinugasa & Kilding (2009) that the use of these strategies resulted in an improved self-reported perceptual recovery.

Rowsell, Coutts, Reaburn & Hill-Haas (2009) studied twenty (20) junior male soccer players and the effects of water immersion (CWI and thermoneutral) on physical test performances and perception of fatigue. Conclusions appear to discourage Cryotherapy as an effective mean of recovery from physical performance loss after exercise. Results do show an improvement vs thermoneutral on perceived fatigue and pain.

Peiffer, Abbiss, Watson, Nosaka & Laursen, (2010) examined the effects of 5 minutes cold-water immersion (14ºC) recovery intervention on repeated cycling performance in the heat in a two-armed randomized controlled trial of older adults (n=77). The authors concluded after observing significantly lowered rectal temperature and maintained endurance performance during subsequent high-intensity exercise that repeated performance may be improved when a short period of cold-water immersion is applied during the recovery phase. However, to note that on regards to economy and Vo2, no significant differences between control and Cryotherapy groups were found.

Stacey, Gibala, Marti, Ginis & Timmons (2010) examined the effects of commonly used recovery interventions (such as CWI) on time trial performance, immune changes, and psychological outcomes of cyclist. The CWI group was subject to water at 10ºC. This team concluded that the use of commonly recovery interventions such as rest, active recovery and Cryotherapy did not affect the decline in cycling performance during repeated bouts of intense exercise. CWI did however improve from a physiological perspective where the athletes felt better after Cryotherapy. The authors speculate that this feel better phenomenon may allow athletes to train harder.

Rowsell, Coutts, Reaburn & Hill-Haas (2011), similarly to their previous study, considered the effectiveness of CWI (cold water immersion) vs HWI (hot water immersion) on thirteen (13) junior soccer players during tournament play.
After the standard post-match recovery, participants in the CWI group immersed their entire body to the mesosternale level for 5x1-min intervals at 10ºC. Compared with HWI, leg soreness and fatigue were lower on CWI while playing successive soccer matches.

Ascensão et al. (2011) have observed twenty-male soccer players (20) that completed one 90 minute soccer match and were randomly divided into Cryotherapy (10 min cold water immersion, 10ºC) and thermoneutral (10 min thermoneutral water immersion, 35Cº) groups. Muscle damage (creatine kinase, myoglobin), inflammation (C-reactive protein), neuromuscular function (jump and sprint abilities), maximal isometric quadriceps strength, and delayed-onset muscle soreness were evaluated before, within 30 min of the end, and 24 and 48 h after the match.

Results show that the cold water immersion group reported less delayed-onset muscle soreness in hip adductors at 30 min, and in calf and quadriceps at 24 h compared with the neutral water immersion again at the same time points. Neuromuscular function was not significantly affected by either CWI or TWI. Nevertheless, isometric strength presented an improvement in the CWI group at 24 hours versus TWI.

Pournot et al. (2011a) investigated the effectiveness of different types of hydrotherapy (TWI, CWI & CWT) on max strength, power and inflammatory response in forty four (44) male elite athletes from Soccer, Volleyball and Rugby. Cold water immersion was performed at 10ºC for 15 minutes.
The authors ultimately concluded that CWI was effective in recovering force loss (1h and 24h for CWI group) and in reducing the inflammatory response that HIT induces.

Williams, Landers & Wallman (2011), on their investigation studied eight (8) well trained males and used CWI trials (one immediately after and other 3 hours after) that consisted of submerging the body to the mid-sternum in water at a temperature of 15°C (± 1°C) for 15 min. Williams reported that the immediate CWI group performed better after a High intensity interval exercise in the next day running performance. However, delayed (3 h) CWI was also likely to result in improved performances when compared to a passive intervention of no CWI. More importantly, DOMS symptoms reduction was associated with immediate and non-immediate CWI at all levels.

Bleakley et al. (2012) on his review regarding cold water immersion, provides some evidence that cold-water immersion reduces delayed onset muscle soreness after exercise when compared with passive interventions involving rest or no intervention. The authors claim there was insufficient evidence to conclude on other outcomes or for other comparisons.

White et al. (2014) investigated the effects of different CWI protocols on inflammatory and functional recovery. They observed eight (8) healthy active males who completed five trials of a high-intensity intermittent sprint protocol.

This was followed by a randomly assigned recovery condition: 1 of 4 CWI protocols (CWI-10 min × 20 °C, CWI-30 min × 20 °C, CWI-10 min × 10 °C, or CWI30 min × 10 °C) versus passive resting. The authors ultimately concluded that CWI following high-intensity intermittent sprint does not significantly reduce plasma markers of inflammation or perceptions of soreness and impairment. The authors affirm that CWI appears to have aided recovery for muscle performance in SSC.

2.3.2) Whole body Cryotherapy (WBC)

WBC consists of exposure to very cold air that is maintained at -100ºC to -190ºC in a special temperature-controlled cryochamber, generally for 2 to 4 minutes (Westerlund, Oksa, Smolander and Mikkelsson, 2004; Ferreira et al. 2014).

It's a recent novelty process (in the context of performance training) and relatively expensive. However, there's some data reporting its effectiveness against exercise induced muscle damage. Banfi et al. (2010) claim that WBC reduces pro-inflammatory responses, decreases pro-oxidant molecular species and stabilizes membranes, resulting in high potential beneficial effects on sports-induced hemolysis, and cell and tissue damage, which is characteristic of heavy physical exercise. Other studies have evaluated the effects of WBC on the recovery from muscle damage.

Hausswirth et al. (2011) conducted a study with three sessions of WBC (3 min at −110°C) after EIMD (exercise induced muscle damage) in eight (8) well-trained runners. Hausswirt et al. (2011) compared the effects of Whole-Body Cryotherapy vs. Far-Infrared vs. Passive Modalities. These authors have concluded that several WBC exposures (3 min at 110ºC) was the best recovery modality to hasten recovery from DOMS with an improved muscle strength, perceived sensation, and also decreased muscle pain versus other groups.
Pournot et al. (2011b) tested trained runners on a damaging simulated trail runs. Endurance trained males (n=11) completed two experimental trials separated by 1 month in a randomized crossover design. One trial involved passive recovery (PR), the other a specific whole body Cryotherapy (WBC) for 96 h post-exercise. This team concluded that a unique session of WBC (3 min at -110ºC) performed

immediately after exercise significantly enhanced muscular recovery by restricting the inflammatory process.

Costello, Algar & Donnelly (2012) investigated the effects of Whole Body Cryotherapy (WBC) on proprioceptive function, muscle force recovery following eccentric muscle contractions and tympanic temperature. Their findings show that one intervention of WBC (2x 3 min at −110°C) applied 24 hours after intensive eccentric exercise in healthy participants (n=36) did not hasten muscle strength nor decrease muscle soreness. In this case WBC might have been applied soon enough for it to induce a significant in fatigue or strength.

Fonda and Sarabon (2013) examined the effects of five WBC exposures (3 min at −140 to −190°C) in pain, biochemical and performance parameters during 5 day recovery period after HIT of the hamstrings. Parameters include: peak torque, rate of torque development, squat jump start power, and decreased muscle soreness. Results were not 100% supportive for the use of WBC. Significant interaction between the control and WBC condition was evident for the rate of torque development ($P<0.05$). Pain measures substantially differed between the WBC and the control condition after the exercise but no other variable experienced significant change.

Ferreira et al. (2015) investigation focused on twenty six (26) young male participants and their reaction to a single WBC session performed immediately after EIMD. Anterior thigh muscle thickness, isometric peak torque, and muscle soreness of knee extensors were measured pre, post, 24, 48, 72, and 96 h following the fatigue protocol which consisted of five sets of 20 drop jumps with 2-min rest intervals between sets. Pain, muscle swelling, and muscle strength presented an improvement at 72 h after EIMD compared with control. In contrast, the control group did not recover from muscle swelling and pain until 96 h following EIMD. Further, muscle strength in the control group was still depressed from baseline 96 h post exercise. The authors concluded that WBC after strenuous exercise may help enhance recovery from muscle damage.

Bleakley et al. (2014) conducted a review on whole body Cryotherapy using data from various investigations. Small randomized studies found that WBC offers improvements in subjective recovery and muscle soreness following metabolic or mechanical overload, but report little benefit towards functional recovery such as strength or power (exception being Hausswirth et al. 2011).

2.3.3) CWI and WBC

A common supposition is that the extreme nature of WBC offers significant advantages over traditional methods of cooling, such as CWI or ice-pack application. However, there is no strong evidence that it offers any distinct advantages over traditional methods of Cryotherapy (Bleakley et al., 2014). CWI and ice-pack application are both capable of inducing clinically relevant reductions in tissue temperature, and that they also provide important physiological and clinical effects (Bleakley et al. 2014). Aside from the obvious discrepancy in temperature and exposure time, one main difference would be the presence of hydrostatic pressure. Although it might have some benefits, its general consensuses that the potential gains from CWI originate from the lower temperature expose rather than pressure (Ascensão et al. 2011).

Another important limitation is that WBC is currently significantly more expensive and less accessible than either CWI or other forms of Cryotherapy (Bleakley et al., 2014). One could also argue that CWI is safer when we consider the temperatures the athletes are subjected to.

Ultimately some discrepancies appear to exist among authors. To note that the most common benefits of both methods seem to revolve around pain relieve sensation, which has an arguable role of extreme importance. Other reports show improvements at maximum strength and power, neuromuscular function and metabolic markers. But although there is some evidence that WBC and CWI improves the perception of recovery and soreness after various sports and exercise, this does not seem to translate into enhanced functional recovery (Bleakley et al., 2014). The psychological maximal effort is not equivalent to the physiological maximal effort during muscle soreness, since it’s important to overcome both physical and mental fatigue during sport. However, these findings may have some significant implications when exercise is performed over a prolonged period of time. Muscular strength and perceived pain are deciding factors when determining when an athlete with exercise induced fatigue should return to normal training loads. Using this premise, if using CWI or WBC sessions, one should also incorporate strength and fatigue evaluations as they are important in assessing the overall functional levels of a subject.

2.3.4) Contraindications

Cryotherapy, while its usage is somewhat controversial, its side effects appear minimal (Banfi et al. 2010), although the impact on adaptation or repeated bout effect has yet to be elucidated (Howatson et al., 2007).Those persons that are very sensitive to cold will not be able to tolerate icing long enough to make any significant effect, and so, should avoid these types of techniques. People with problems in the blood vessels near the skin should also avoid cold therapy, especially those with Raynaud's phenomenon (a condition in which the blood vessels in the fingers, toes, ears and nose constrict dramatically when exposed to cold and other stimuli). Cold allergic conditions, areas of impaired sensation, open wounds, anemia, diabetes and heart disease are also very discouraged. On the matter of training immediately after Cryotherapy, some authors disapprove.

Sellwood et al. (2007) reported that Cryotherapy applied before a strength training session decreases muscular performances and increases the probability of injury. Versey et al. (2013) findings support such claims. The authors declare that if exercise is performed soon after (<45 min) cold water immersion, it may decrease exercise performance, particularly if the exercise is high-intensity or explosive in nature. This might be explicated by the increase of the time of spike trains and lesser impulse transmission frequencies, originating lower contraction speeds that affect overall force production and proprioception.

Other authors found no harm in intermittent Cryotherapy applied mid training. Borgmeyer, Scott & Mayhew (2004), claim that Cryotherapy before strength training does not impact performance negatively and can be used before intense exercise. This is supported by other studies such as the one by Thornley, Maxwell & Cheung (2003). These authors affirm that no evidence was found on knee extension max torques when preceded by cold water immersion. Rubley, Denegar, Buckley & Newell (2003) have also not found any significant differences on sub maximal strength immediately after CWI. Cryotherapy after training has not reached a consensus but recent investigations seem to report it affects performance negatively so it should be undertaken with care.

Dugué et al. (2005) studied and compared the effects of WBC and winter swimming on anti-oxidative capacity. The authors examined twenty (20) healthy active women grouped by similar characteristics (Body mass, height, age, physical activity, etc.).The WBC group was subject to exposure to -110ºC for a total of 2 minutes for three times a week. The authors concluded Cryotherapy and winter swimming for 3 times a week does not appear to be harmful as far as anti-oxidative capacity is concerned.

Banfi et al. (2010) also concluded that WBC was not harmful and does not induce general or specific negative effects in athletes. The WBC treatment does not induce modifications of biochemical and hematological parameters. Bleakley et al. (2014) examined the biochemical, physiological and clinical effects of WBC using data from several controlled trials. These authors claim that no adverse effects were associated with WBC. However, there were no active surveillance of predefined adverse events and, as such, athletes should opt for less expensive modes of Cryotherapy.

Silva (2013) examined the possible negative effects of cold on the proprioception and motor sensorial response. Forty (40) participants were distributed initially and randomly between experimental group and control group. The experimental group was submitted to a dynamic program with ice for 10 minute and control conducted passive recovery, both prior to evaluations. Maximum force, force sense and the functionality of the limb were examined soon after. The author results were not statistically significant for all tests conducted, so cold did not negatively influence performance

Although possibly beneficial in the short term, it is unknown if suppressing the acute inflammatory response can affect negatively the muscles ability to adapt to exercise (Ferreira et al. 2014). Further investigation on this matter should be compiled before a finite conclusion is reached. Applying Cryotherapy at the end of training or competition appears otherwise safe, as in these conditions the potential reported side effects of Cryotherapy become irrelevant.

2.3.5) Time, Timing and Temperatures

The temperature and exposure were examined from several authors who used Cryotherapy on their studies. Versey et al. (2013) compiled data regarding cold water immersion and issued practical recommendations. It was observed that temperatures ranged from 5ºC to 20 ºC but 10-15ºC were reported as the most common. It appears, however, that the total time of immersion may be more influential with a total immersion duration of at least 10 minutes being more effective than shorter durations (i.e. 5-6 min) at inducing substantial positive change. In athletic populations, a temperature range of between 10ºC-15°C has been recommended to ensure that CWI protocols are well tolerated (Halson, 2011).

Douglas et al. (2014) have reported that CWI for 10 min at 10 °C appears to be the most useful CWI timeframe/temperature for restoring performance to their original levels. Regarding total immersion time, it typically ranges from 2-20 minutes or multiple shorter immersion (1-5 min) separated by a period of time out of the water. In cold climates, the water in rivers, lakes, oceans and out of the tap may be <20ºC making a cheap and efficient substitute. The timing in which CWI post-exercise is applied may also influence any effects on performance recovery. Nonetheless, most studies have commenced water immersion within 30-min post exercise with only few authors reporting using Cryotherapy mid training or in longer periods after training.

Williams et al. (2011) are ones to have studied and compared the effect of immediate versus delayed CWI on recovery of exercise performance. They have reported that 15 min in 15 ºC water to midsternal level provided greater recovery benefits in team sport athletes when undertaken immediately when compared with 3 h post-exercise. Performing CWI 3 hours after exercise was still likely to improve recovery, however it stands to reason that WBC applied 24h after exercise may be too late to have a beneficial physiologic response (Vaile et al., 2008; Ferreira et al., 2014).

3. Objectives and Hypothesis

3.1 General Objectives and Variables

When an athlete performs regular exercise, recovery strategies are, in most cases, present. Cryotherapy is a potentially effective method for reducing the post-training fatigue that high intensive training and competition induce. As previously mentioned, this study incorporates information on CWI and WBC Cryotherapy modalities.

The general objective of this investigation was to verify if there are any significant differences between passive recovery (PR), whole body Cryotherapy (WBC) and cold water immersion (CWI) on performance recovery in trained athletes. With this in mind, we can define independent variables as:

- Passive Recovery;
- Cold Water Immersion;
- Whole Body Cryotherapy;

Several markers of exercise induced muscle damage have been analyzed and compared in multiple time points and among different groups. The dependent variables that have been considered were:

- Maximum Isometric Voluntary Contraction (quadriceps and hamstrings);
- Squat and Counter Movement Jump;
- Discomfort Perception (quadriceps, hamstrings, calf and gluteus);

These markers have been used in several studies and are considered as determinant to provide the answers pursued. On this principle, some hypotheses were defined in an attempt to predict the behavior of the variables.

3.2) Hypothesis

Three Hypotheses were elaborated:

1. Cryotherapy (CWI) improves recovery from exercise-induced muscle damage when compared with Passive Recovery.

2. Cryotherapy (WBC) improves recovery from exercise-induced muscle damage when compared with Passive Recovery.

3. CWI and WBC induce similar results on recovery from exercise-induced muscle damage.

The term “recovery” includes the performances for maximum isometric voluntary contractions, personal perception of discomfort and the vertical jump results, when compared with their baselines levels on 2 different time points (24 h and 48 h). It’s subjective to the extent of the interpreter of the results. This means that the readers may not share the same opinions, as the context in which the results may be applied isn’t available in the study.

3.3) Specific objectives

- Compare the maximum isometric voluntary contraction torques of the quadriceps and hamstrings of the experimental groups and the control group, before the fatigue protocol (to assess baseline values) and afterwards at the 24 and 48 hour marks. The logic lies on determinate the torque loss on each day and define how well the maximum strength recovers between days;

- Compare the squat jump values between the control and the experimental groups. First before the fatigue protocol (baseline) and at 24 and 48 hours after. The objective is to determinate the height loss between days and thus assessing the degree of recovery on a pure concentric movement (explosive power);

- Compare the counter movement jump performance decrease between CWI, WBC and control groups at 3 different time points: Baseline, 24 hours and 48 hours after the fatigue protocol. The point is to witness how a SSC ability highly dependent on neuromuscular function behaves with presence of fatigue;

- Compare personal subjective discomfort sensations, between groups, at the 24 and 48 hours after the fatigue protocol. No baseline is required as all participants are required to report healthy at the start. The goal is to reveal if there's a clear impact of Cryotherapy (WBC & CWI) on discomfort perception when compared to control participants.

3.3) Study Limitations

1. While the sample homogeneity is something desired it also limits the context in which the conclusions are applied. Our experiment had only trained males and, as such, our findings can only be applied to such individuals.

2. Our follow-up only had 2 time points: 24 and 48 hours (excluding the baseline evaluation). This is a potential limitation because while recovery happened within this timeframe, it's known that DOMS can last longer than 72 hours. Duo to time limitations we were unable to extend the follow-up periods.

3. A sample size of forty (40) participants is small to draw conclusions. However, the sample had quality as the participants were highly trained national level athletes that are not as commonly found in cryotherapy studies.

4. The fatigue protocol was original and is not directly comparable with other fatigue inducing protocols. The diversity of fatigue protocols in the literature include: competition, yo-yo tests, drop jumps, isokinetic protocols, aerobic exhaustion, among others. None of the protocols appeared exhaustive enough to induce DOMS on our highly trained sample, so the fatigue protocol had to be made from scratch. Further studies would incorporate this protocol to determine the reliability of the results.

5. Our Cryotherapy treatments were applied slightly later than most studies. While most authors start 10 minutes after intensive exercise, we waited 30 minutes after the conclusion of the fatigue protocol. This was mostly caused by logistic reasons

4. Material and Methods

4.1) *Instrumentarium*

Participants Anthropometric Evaluation:

- Digital Scale (Figure 4)
- Metric Tape (Figure 4)

Figure 4– Digital Scale and Metric Tape used.

Functional Tests:

- Isokinetic Dynamometer – Biodex (Figure 5).
- Vertical Jump platform (Figure 6).
- Perception of Discomfort Scale (Figure 7).
- Leg Press (Figure 8).

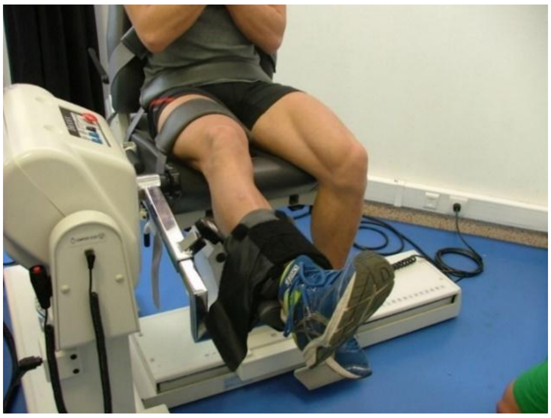

Figure 5 – Isokinetic Dynamometer positioned at 60 degrees.

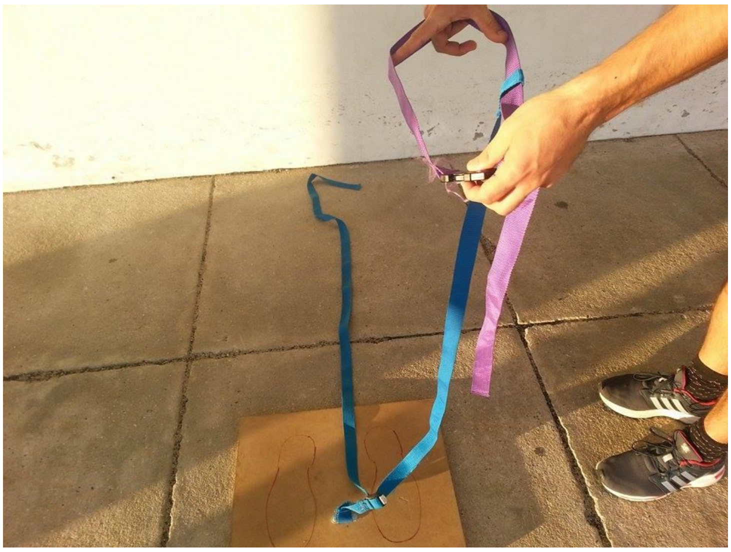

Figure 6 – Platform used for the Vertical Jump evaluations.

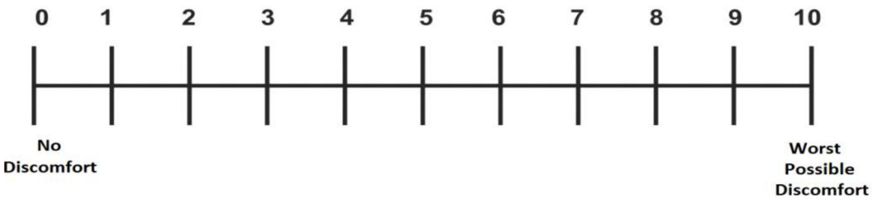

Figure 7 – Discomfort Visual Scale (adapted from Huskisson, 1974).

Figure 8 – Leg Press Device.

Cold Water Immersion:

- Barrel (Figure 9).
- Water Thermometer (Figure 10).

Figure 9 – Athlete in barrel being subject to Cold Water Immersion.

Figure 10 – Water thermometer used.

Whole Body Cryotherapy:

- Cryochamber (Figure 11).

Figure 11 – Whole body Cryotherapy in Cryochamber.

4.2) Participants

Forty (40) trained males from a national level track and field team were invited to participate in the study. All the athletes were gathered one week prior for explanations and clarifications. The study design was presented to the participants which were informed about the objectives and the risks. The participants were randomly assorted for three groups: CWI Group (10), WBC (10) Group and Control Group (20).

The following data were collected: Height (m), Weight (kg), Age (years), Training Experience (years) and Practices per week (n).

- Height was measured with participants facing away from a wall, with their backs pressed. The participants had their shoes removed as to not overestimate the results.
- Weight was measured using a standard nominal digital scale with the participants wearing only underwear.
- Age, Training Experience and Practices per week were filled in by oral questioning.

The athletes were free of injury and illness at the time of testing and during the course of the study. It was proposed to the athletes that they did not have any kind of intensive physical activity during the course of the experiment, as well as to refrain from abnormal changes in the daily routine (such as diet/drugs). This was guaranteed seeing as the trial was conducted during the athletic season transition (from indoor to outdoor) where the athletes had 2 weeks without training and were in their physical conditioning peak. During the course of the experiment, no unorthodox changes to the usual lifestyle pattern were reported by any of the participants.

4.2.1) Control Group

Twenty trained male participants (N = 20) were randomly allocated to the control group. This group did not undertake any special kind of treatment post fatigue (PR) and its characterization is described at Table 1.

Table 1 – Characterization of the Control group

	N	Minimum	Maximum	Mean	Std. Deviation
Age (years)	20	18	23	20.35	1.35
Weight (kg)	20	68.6	88.9	74.36	4.72
Height (m)	20	1.7	1.86	1.77	0.04
Training experience (years)	20	2	7	4.65	1.38
Practices per week (n)	20	6	6	6	

We can discern the categories: Age, Weight; Height; Training experience and Practices per week. Regarding the subject's age, it ranged from 18 (minimum) to 23 (maximum) with a mean of 20.3 ± 1.3 years. Weight showed a minimum of 68.6 kg and a maximum of 88.90, averaging to 74.3 ± 4.7 kg. The differences in height went from 1.70 minimum to 1.86 meters maximum, with a mean of 1.76 ± 0.04. As for years of practice, a range from 2 to 7 years was reported, with an average of 4.6 ± 1.3 years. Practices per week were constant at 6 days for all participants.

4.3.2) Cold Water Immersion Group (CWI)

The CWI group was formed by 10 trained males (N=10), that, as the name implies, received treatment in the form of cold water immersion. This group's respective characterization can be found at Table 2.

Table 2 – Characterization of the CWI group

	N	Minimum	Maximum	Mean	Std. Deviation
Age (years)	10	18	22	19.9	1.37
Weight (kg)	10	64.7	87.5	75.38	6.21
Height (m)	10	1.62	1.84	1.768	0.05
Training experience (years)	10	4	8	5.1	1.19
Practices per week (n)	10	6	6	6	

Considering the same categories used previously, we can confirm ages range went from 18 to 22 years old, with an average of 19.9 ± 1.3 years old. As for weight, the minimum was 64.7 kg, the maximum 87.5 kg, while the mean 75.3 ± 6.2 kg. Regarding the participants height, the minimum reported was 1.62 meters, while the maximum rounded the 1.84 meters. The mean was 1.76 ± 0.05 meters. The subject's training experience minimum was 4 with an 8 year experience maximum, with a mean index of 5.1 ± 1.1 years. Exactly like the control group, practices per week per athlete were 6 days.

4.2.3) Whole Body Cryotherapy Group (WBC)

The WBC group was subject to another variant of Cryotherapy: high intensity Cryotherapy. This group was composed of the remaining males (N=10) and their respective characterization is detailed at Table 3.

Table 3 – Characterization of the WBC group

	N	Minimum	Maximum	Mean	Std. Deviation
Age (years)	10	19	23	21	1.41
Weight (kg)	10	62.4	83.1	73.84	6.06
Height (m)	10	1.63	1.83	1.755	0.06
Training experience (years)	10	2	6	4.2	1.31
Practice per week (n)	10	6	6	6	

Regarding Age, we notice a minimum of 19, a maximum of 23 and an average of 21 ± 1.4 years Height shows a minimum of 62.4 kg, a maximum of 83.1 kg and an average of 73.8 ± 6.0 kg. For years of practice, the minimum reported was 2 years, the max 6 years, and the mean was 4.2 ± 1.3 years. Practice per week was constant at 6 days like in the previous groups. To locate if significant difference was present, an ANOVA analysis of variance was performed and may be found at the next section (Table 4).

4.2.4) Characterization Differences

No significant differences were found among groups for age ($F(2, 37) = 1.63$, $p = 0.20$), weight ($F(2, 37) = 0.20$, $p = 0.81$), height ($F(2, 37) = 0.28$, $p =$

0.75), training experience (F (2, 37) = 1.15, p = 0.32), and practices per week (Table 4). Statistical analysis showed the homogeneity among groups for all the selected variables.

Table 4 – Characterization Differences

		Degrees of Freedom	F	Sig.
Age (years)	Between Groups	2	1.63	0.2
	Within Groups	37		
	Total	39		
Weight (kg)	Between Groups	2	0.2	0.81
	Within Groups	37		
	Total	39		
Height (m)	Between Groups	2	0.28	0.75
	Within Groups	37		
	Total	39		
Training Experience (years)	Between Groups	2	1.15	0.32
	Within Groups	37		
	Total	39		

4.3) Experimental Design and Procedures

In order to meet the goals proposed, this experimental design was devised. The schematic representation is provided in Figure 12 and has been created with the information compiled from the literature revision in accordance to the proposed objectives.

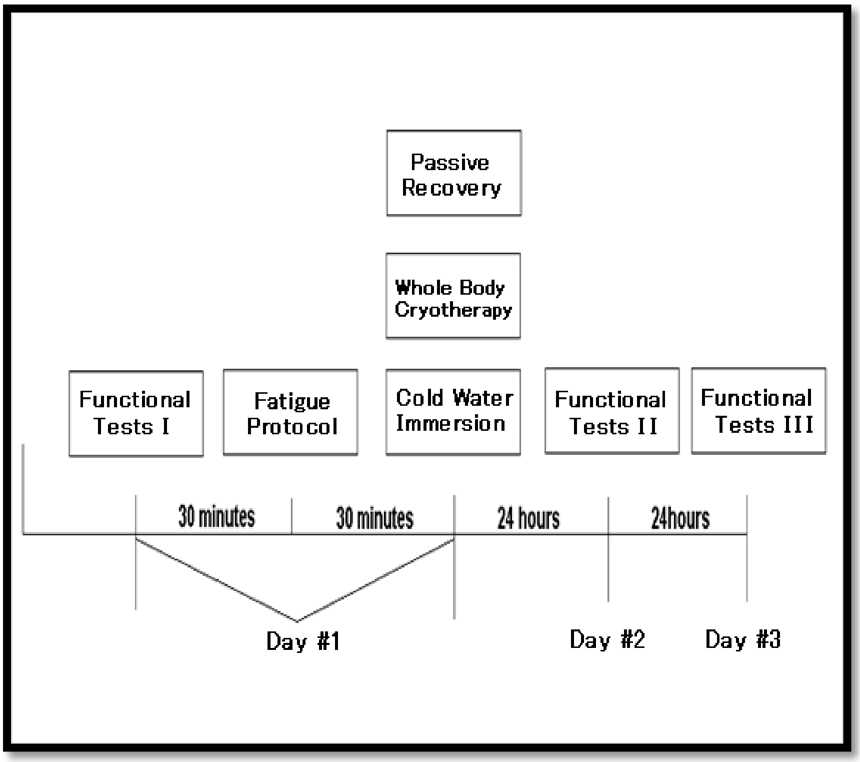

Figure 12 – Chronological timeline of the investigation.

The first stage of the study was conducted 1 week prior to the data collections. This week was used to explain the study specifications to the participants. An anthropometric and experience evaluation of the athletes was conducted once they were absent of doubts. The variables collected were: Age, Weight, Height, Time of practice and Practices per week. One week later, the experimental study properly begins with the first set of functional tests (I). The functional tests are a group of examinations that intended to provide a quantifiable value for performance. These sorts of tests are widely used and the objective was to provide a baseline of values without presence of fatigue (Functional tests I), which would later be compared with data with some fatigue (Functional tests II and III), therefore objectively measuring the performance decline.

The fatigue protocol was initiated 30 minutes after the baseline assessment. The fatigue protocol was based on the DOMS etiology and compiled heavy eccentric, high volume unaccustomed exercise, meant to cause some degree of muscle damage. Afterwards, the participants divided themselves into groups and took on a different recovery method.

The participants were divided in 3 groups each with a different recovery model. The three recovery methods were Passive Recovery (PR), Cold Water Immersion (CWI) and Whole Body Cryotherapy (WBC) and were meant to control and measure if any recovery benefits were associated with Cryotherapy.

The participants were instructed to return in 24 hour increments to reevaluate the functional tests (II and III).

4.3.1) Functional Tests - Subjective Discomfort Evaluation

Chronologically, the first of the functional tests conducted. It was added on the basis that pain or discomfort affects performance, and, since the most widely accepted mechanism associated with Cryotherapy is the cooling-induced reduction of pain perception (Ascensão et al. 2011), it makes sense to include it. A simple subjective discomfort evaluation was conducted for 4 distinct muscle groups: quadriceps, hamstrings, calf and gluteus. These were the most affected muscles by the fatigue protocol (see fatigue protocol 4.3.4) and its values were recorded at 24 and 48 hours. The athletes reported the number that was the most appropriate to the discomfort felt at the moment of evaluation. An analog visual scale adapted from Huskisson (1974) was used (see Instrumentarium at 4.1). It ranged from 0 (no discomfort) to 10 (worse discomfort possible).

This test was meant to assess if any noticeable differences in discomfort were present between groups, after relatively long periods of time (to up to 48 hours). One cannot forget that different participants naturally possess different perceptions of discomfort, which might affect the accuracy of the reports.

4.3.2) Functional Tests – Squat Jump and Counter Movement Jump

The vertical jumps were the second evaluation conducted and its purpose was to help evaluate the power and the elastic proprieties of the muscle and its behavior in fatigue conditions. Two kinds of jumps, Squat and Counter Movement, were performed by the participants. Jumping may use the SSC, such as a countermovement or drop jump, or not, as is the case of the squat jump.

Both were executed on a special wood platform, which the athletes had previously been introduced on. The athletes were strapped to a belt at the waist which was linked to the platform. A clip was placed on the tape feeder and, while performing the jump, the clip moved depending on the jump height. Afterwards, we measured the distance the clip traveled from the original position to discover the jump altitude. This method accurately measures the jump height and is knows as an adaptation of the University of Toronto Belt Jump (KLAVORA, 2000).

As for each jump specifications, in the squat jump, the participants were instructed to jump from a 90 degree knee angle, with feet at shoulder width and hands at the hip (Figure 13). From this position, the participants maintained the position for 3 seconds before extending their legs (concentric phase) in order to achieve the maximum height. Special notice was undertaken so the participant's feet were hyper extended at the lift moment of the jump, and also so that no significant counter movement (eccentric phase) was evident. The SJ has been previously validated as a reliable measure of lower limb power.

Figure 13 – Subject performing the squat jump. Arrow describes the direction of the movement.

For the Counter movement jump, the Abalakov jumping protocol was applied (Klavora, 2000). All the participants had the feet firmly on the platform, with the knees creating a 180 degree angle, with the hands loose. Once the athlete started the jumping motion, the knees flexed (Eccentric phase) and immediately extended back (Concentric phase) to perform the jump (Figure 14). The depth of the countermovement was self-selected and represented each participant's optimal angle for jumping. Contrarily to the squat jump, the arms were lose and could help with the counter movement. Special notice to the hyperextension of the feet was also taken.

Figure 14 – Subject performing a CMJ. Arrows describe the direction of the movement.

Each athlete performed 2 jumps of both SJ and CMJ and the best performance was recorded for analysis. The jumps heights were evaluated at different time points:

- At resting conditions (baseline).
- Roughly 24 hours after the conclusion of the fatigue protocol.
- At 48 hours after the fatigue protocol.

4.3.3) Functional Tests – Maximum Isometric Voluntary Contraction

Maximum Isometric Voluntary Contraction (MIVC) is a standard test in fatigue investigations. Knee extension and flexion strength was determined via isometric contraction on a dynamometer. The objective was to quantify the maximum strength of the quadriceps and hamstrings muscles. Rather than raw performance, what was desired was the subsequent performance loss after the fatigue protocol.

The evaluation was conducted third chronologically and was performed at the Biomechanical Laboratory of University of Porto (LABIOMEP), on an isokinetic dynamometer (Biodex). The athletes, after warming up, with the dominant leg knee positioned at 60º degrees of flexion, arms folded across their chest, and securely strapped (with the aid of chest and thigh straps), completed two maximal repetitions for the quadriceps (extension) and hamstrings (flexion). The exercise was performed unilaterally at only the dominant leg. Each contraction was separated by 1 minute and 30 seconds rest and lasted for 5 seconds. The participants were verbally encouraged to achieve their best performance.

The peak torque of the two series was recorded (two for each muscle group). The athletes performed this evaluation on 3 different points in time:

- On the first day, rested, to assess their respective baseline torque.
- On the second day, 24 hours after the fatigue protocol.
- On the third day, 48 hours after the fatigue protocol.

4.3.4) Fatigue Protocol

The fatigue protocol was structured to induce exercise muscle damage. To achieve this on highly trained individuals, 3 x 100 repetitions (weight set at 80% of each individual body weight) were conducted on leg press equipment.
The rest between series was 1 minute. During the protocol, the athletes were instructed to give emphasis to the eccentric phase of the contraction, aiming for a 3:1 seconds ratio with the concentric contractions.

As mechanical stress is known to cause serious damage to myofibrils during eccentric contractions (Proske and Morgan, 2001), it was guaranteed that significant mechanical damage was present. The volume was significant, with the eccentric phase of the movement highlighted and conducted on equipment the athletes were not too accustomed in. The muscle stress during leg press includes quadriceps, hamstrings, gluteus and calf.

4.3.5) Recovery Protocols (CWI, WBC and PR)

The control group performed passive rest (PR). These participants did not accept any form of intervention or treatment, and continued with their normal habits after the fatigue protocol. This group is especially important, as it allows for a clear comparison between untreated subject data versus treated.

For cold water immersion, the treatment started 30 minutes after the fatigue protocol, with the athlete's lower limbs submerged in a barrel filled with cold water. The water temperature was kept constant at 10ºC (± 1ºC) and the duration was 10 minutes. Several studies have recommended these temperatures for CWI studies (Bailey et al., 2007; Jakeman et al., 2009 Stacey et al., 2010; Ascensão et al., 2011 Roswell et al., 2011; Halson, 2011; Versey et al. 2013). As for the duration, it's in the range suggested by Versey et al. (2013) and Douglas et al. (2014). The water was regulated using several ice packs (to cool) and tap water (to warm), successfully keeping the temperature constant at the 10º ± 1º C range. The time and temperatures were based on the research conducted during the literature review and were controlled at regular intervals using a water thermometer.

The WBC group participants were relocated to a nearby clinic 30 minutes after exertion. The athletes were asked to strip, leaving only their socks and underwear. Afterwards, they proceeded to enter a cryochamber, a compartment that is cooled using liquid nitrogen to achieve temperatures of up to -190ºC. The participants withstood temperatures in the -150ºC to -190ºC range for exactly 2 minutes. The intensity and duration of the treatment were based on research conducted at the literature review.

4.4) Statistics

SPSS version 21.0 was used for all statistical analyses, with statistical significance set at 0.05. Descriptive statistics were included on all data so the reader can understand the context in which the values are presented. For descriptive statistics, means, standard deviations and minimum and maximum were included. A repeated-measures analysis of variance (ANOVA) was used to establish differences between treatments over time. Degrees of Freedom, F and P values were included in the ANOVA tables. When significant p values were observed, a Bonferroni adjustment was applied for post-hoc comparisons.

5. Results

5.1) Subjective Discomfort Evaluation

A discomfort test was conducted to see if perceptions were significantly different among groups. The evaluation followed the specifications shown previously in section 4.3.1 for four muscle groups: quadriceps, hamstrings, gluteus and calf.

5.1.1) Quadriceps

Table 5 shows the index of subjective discomfort for the *quadriceps femoris*.

Table 5 - Quadriceps: Index of discomfort

		N	Mean	Std. Deviation	Minimum	Maximum
24 hours after exertion	Control	20	7.5	1.23	3	9
	WBC	10	7	1.24	4	8
	CWI	10	6.9	0.73	6	8
	Total	40	7.22	1.14	3	9
48 hours after exertion	Control	20	7.05	1.46	2	9
	WBC	10	3.5	1.35	1	5
	CWI	10	2.2	0.91	1	4
	Total	40	4.95	2.53	1	9

Values are expressed within 1 (minimum) and 10 (maximum) in the discomfort scale.

The CWI group presented, at 24 hours, an average index of 6.9 ± 0.7 on the discomfort scale. The WBC participant's group response was similar (7 ± 1.2). The Control group showed a slightly higher index (7.5 ± 1.2). According to the data, no significant differences were evident 24 hours after exertion.

Forty eight hours after exertion, significant differences were found among groups. Control subject's perception of discomfort appears to be higher than CWI and WBC, with no significant decrease in discomfort perception at 24 hours (7.5 ± 1.2 to 7.0 ± 1.4). The maximum index reported (9.0) was the same at 24 and 48 hours. Cryotherapy groups both have decreased their mean indexes considerably. WBC shows a decrease from 7 ± 1.2 to 3.5 ± 1.3, while CWI also presents lower average discomfort ratings with 2.2 ± 0.9 (previously 6.9 ± 0.7), achieving the lowest mean between groups. Maximum and Minimums have both also decreased in the Cryotherapy groups at 48 hours.

An ANOVA repeated measures test was conducted to determine if any of these represent any significant differences (Table 6).

Table 6 - Quadriceps: Data Differences

		Degrees of Freedom	F	Sig.
24 hours after exertion	Between Groups	2	1.18	0.31
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	52.57	0
	Within Groups	37		
	Total	39		

At 24 hours, no significant differences were present seen between groups ($F(2, 37) = 1.18$, $p = 0.31$). This infers a lack of benefit in using either Cryotherapy methods to decrease discomfort at the early stages of recovery. However, that was not the case at 48 hours, where significant differences were seen among groups ($F(2, 37) = 52.57$, $p = 0$). A Bonferroni was conducted to detail which exact group differ from another at 48 hours.

Table 7 - Quadriceps: Post Hoc Bonferroni (48 h)

(A) Group	(B) Group	Mean Difference (A-B)	Sig.
Control	WBC	3.55	0
	CWI	4.85	0
WBC	Control	-3.55	0
	CWI	1.3	0.10
CWI	Control	-4.85	0
	WBC	-1.3	0.10

A detailed analysis shows a statistical difference between control and CWI ($p = 000 < 0.05$), as well as control and WBC groups ($p = 000 < 0.05$). As for CWI opposed to WBC, no significant differences were noted ($p = 0.10$). This suggests that at 48 hours, participants who had used CWI or WBC had decreased perceived discomfort of the quadriceps compared with PR.

5.1.2) Hamstrings

Table 8 shows the index of subjective discomfort for the Hamstrings.

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Table 8 - Hamstrings: Index of discomfort

		N	Mean	Std. Deviation	Minimum	Maximum
24 hours after exertion	Control	20	3.95	1.05	2	6
	WBC	10	3.1	0.73	2	4
	CWI	10	3.4	0.96	2	5
	Total	40	3.6	1	2	6
48 hours after exertion	Control	20	1.65	0.81	0	3
	WBC	10	1.3	0.67	0	2
	CWI	10	1.6	0.69	1	3
	Total	40	1.55	0.74	0	3

Values are expressed within 1 (minimum) and 10 (maximum) in the discomfort scale.

At 24 hours, the CWI group presents a mean index value of 3.4 ± 0.9 in the discomfort scale. The WBC participants display a similar mean of 2.9 ± 0.7, while the Control athletes, a mean of 3.9 ± 1. Minimum discomfort was constant at 2 for all groups.

At 48 hours, a near complete absence of discomfort can be deducted by an average index of 1.6 ± 0.8 presented by the CWI participants, 1.3 ± 0.6 by the WBC group and 1.6 ± 0.8 by the control group. Maximum and minimum index values decreased from 24 to 48 hours as well, suggesting early recovery. While no differences appear apparent, the population was tested for differences using the previous ANOVA variance test. Its results may be found at Table 9.

Table 9 - Hamstrings: Data Differences

		Degrees of Freedom	F	Sig.
24 hours after exertion	Between Groups	2	2.89	0.06
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	0.74	0.48
	Within Groups	37		
	Total	39		

No statistical significant differences were present among groups. At post 24 hours, an F value of 2.89 and a p value of 0.06 shows that no statistical significant differences exist at 24 hours. Likewise, at 48 hours, no significant statistical differences were present ($F(2, 37) = 0.74$, $p = 0.48$). Our data shows no proof of Cryotherapy having a clear impact on discomfort perception of the hamstrings, at neither 24 nor 48 hours.

5.1.3) Calf

Table 10 shows the index of subjective discomfort for the Calf (*soleus* and *gastrocnemius*).

Table 10 - Calf: Index of discomfort

		N	Mean	Std. Deviation	Minimum	Maximum
24 hours after exertion	Control	20	4.9	0.96	3	7
	WBC	10	4.4	0.84	3	6
	CWI	10	4.8	1.22	3	7
	Total	40	4.75	1.00	3	7
48 hours after exertion	Control	20	2.3	0.97	1	4
	WBC	10	1.8	0.63	1	3
	CWI	10	2.2	1.03	1	4
	Total	40	2.15	0.92	1	4

Values are expressed within 1 (minimum) and 10 (maximum) in the discomfort scale.

Data for Calf shows that all groups, at 24 hours, reported a total mean index of 4.75 ± 0.1 in the discomfort scale, specifically 4.9 ± 0.9 (Control), 4.4 ± 0.8 (WBC) and 4.8 ± 1.2 (CWI). These similar ratings are slightly improved at 48 hours with a total mean index of 2.1 ± 0.9, with 2.3 ± 0.9 to control, 1.8 ± 0.6 to WBC and 2.2 ± 1 to CWI. There appears to be no differences present. Regardless, an ANOVA repeated measures test was conducted, and its respective results are present at Table 11.

Table 11 - Calf: Data Differences

		Drees of Freedom	F	Sig.
24 hours after exertion	Between Groups	2	0.83	0.44
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	1.00	0.37
	Within Groups	37		
	Total	39		

The analysis of variance conducted showed no significant differences at neither 24 ($F(2, 37) = 0.83$, $p = 0.44$) nor 48 hours ($F(2, 37) = 1.00$, $p = 0.37$). This means calf discomfort was not affected by neither CWI nor WBC methods.

5.1.4) Gluteus

Table 12 shows the index of subjective discomfort for the Gluteus.

Table 12 - Gluteus: Index of discomfort

		N	Mean	Std. Deviation	Minimum	Maximum
24 hours after exertion	Control	20	5.3	1.17	3	8
	WBC	10	5.0	1.15	3	7
	CWI	10	4.8	1.39	2	6
	Total	40	5.1	1.21	2	8
48 hours after exertion	Control	20	2.2	0.95	1	4
	WBC	10	2.5	0.97	1	4
	CWI	10	2.0	1.05	1	4
	Total	40	2.22	0.97	1	4

Values are expressed within 1 (minimum) and 10 (maximum) in the discomfort scale.

At Table 12, at 24 hours, one can notice similar values between groups. The control group presents a mean index of 5.3 ± 1.1, the WBC an average index of 5 ± 1.1 and the CWI a mean index of 4.8 ± 1.3 on the discomfort scale. At 48 hours, a uniform decrease in discomfort is seen in the values of all the groups. Control with a mean index of 2.2 ± 0.9, WBC with a mean index of 2.5 ± 0.9 and CWI with an average index of 2.0 ± 1. Also, at 48 hours, the maximum (4) and the minimum (1) were exactly the same among groups. An ANOVA repeated measures test was conducted to determine if these values produced significant differences among groups (Table 13).

Table 13 - Gluteus: Data Differences

		Degrees of Freedom	F	Sig.
24 hours after exertion	Between Groups	2	0.59	0.55
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	0.66	0.52
	Within Groups	37		
	Total	39		

The ANOVA test shows that at 24 hours, no differences were present among groups (F (2, 37) = 0.59, p = 0.55). At 48 hours, the same tendency is displayed (F (2, 37) = 0.66, p = 0.52). This data suggests that CWI and WBC treatments have had no effect on neither groups Gluteus discomfort values.

5.2) Maximum Isometric Voluntary Contraction

To evaluate maximum strength, MIVC of the Quadriceps (Leg extension) and Hamstrings (Leg flexion) were conducted. The evaluation followed the specifications shown previously (section 4.3.3).

5.2.1) Leg Extension

The results for isometric leg extension are described in Table 14.

Table 14 – Leg Extension Performance

		N	Mean	Std. Deviation	Minimum	Maximum
Baseline	Control	20	342.1	55.66053	233	458
	WBC	10	318	46.64285	257	381
	CWI	10	338.4	43.53338	276	404
	Total	40	335.15	50.51354	233	458
24 hours after exertion	Control	20	275.85	47.9652	190	355
	WBC	10	273.3	39.21182	222	336
	CWI	10	290.8	40.30936	239	367
	Total	40	278.95	43.58602	190	367
48 hours after exertion	Control	20	266.1	48.62412	178	359
	WBC	10	311	42.87449	247	366
	CWI	10	325	42.31102	270	388
	Total	40	292.05	52.00934	178	388

Values are expressed in Newton/meter (N/m).

Table 14 shows a general decrease in mean leg extension performance from baseline to 24 and 48 hours for all groups. The WBC group presents a baseline value of 318 ± 46.6 N/m which decreases to 273.3 ± 39.2 N/m after the first 24 hours. At 48 hours, the WBC participants showed a slightly improvement from the previous day, 311 ± 42.8 N/m, close to the baseline level. CWI athletes follow a similar trend with an average of 338.4 ± 43.5 N/m for baseline values which deteriorate to 290.8 ± 40.3 N/m 24 hours after exertion. The performance improves at 48 hours to 325 ± 42.3 N/m, relatively close to the baseline performance. Nonetheless, while WBC and CWI groups attained their fatigue peak after 24 h and recovered the basal values after 48 h, control participants showed a significant decrease after 24 h and a further performance slight decrease after 48 h (342.1 ± 55.6 N/m to 275.8 ± 47.9 N/m and to 266.1 ± 48.6 N/m).

Table 15 shows the differences between groups.

Table 15 – Leg Extension: Data Differences

		Degrees of Freedom	F	Sig.
Baseline	Between Groups	2	0.77	0.46
	Within Groups	37		
	Total	39		
24 hours after exertion	Between Groups	2	0.49	0.61
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	6.65	0.00
	Within Groups	37		
	Total	39		

Baseline values are not significantly different for all groups (F (2, 37) = 0.77, p = 0.46). After 24 h the groups showed a similar trend (F (2, 37) = 0.49, p = 0.61), while after 48 h a significant difference is (F (2, 37) = 6.65, p = 0.00) evident. A Bonferroni analysis was conducted to determine which groups differentiate at 48 h (Table 16).

Table 16 – Leg Extension: Post Hoc Bonferroni (48h)

(A) Group	(B) Group	Mean Difference (A-B)	Sig.
Control	WBC	-44.90	0.04
	CWI	-58.90	0.00
WBC	Control	44.90	0.04
	CWI	-14	1
CWI	Control	58.90	0.00
	WBC	14	1

Table 16 shows that after 48 h the control group is significantly different from WBC (p = 0.04) and CWI (p = 0.00), respectively. This leads to the assumption of an increased recovery by the Cryotherapy groups when faced with control. No significant differences were found between the two Cryotherapy groups.

5.2.2) Leg Flexion

Statistics of the results for leg flexion are described in Table 17.

Table 17 – Leg Flexion Performance

		N	Mean	Std. Deviation	Minimum	Maximum
Baseline	Control	20	178.05	31.26	111	237
	WBC	10	179.2	31.93	117	234
	CWI	10	180.7	26.80	122	221
	Total	40	179	29.63	111	237
24 hours after exertion	Control	20	159.85	28.65	101	221
	WBC	10	162	29.19	101	201
	CWI	10	164.6	26.06	111	209
	Total	40	161.57	27.51	101	221
48 hours after exertion	Control	20	167.4	31.14	114	234
	WBC	10	173.1	30.68	116	228
	CWI	10	175.8	29.70	117	227
	Total	40	170.92	30.11	114	234

Values are expressed in Newton/meter (N/m).

Performance values decreased at 24 h for all groups. Control group showed a mean of 178 ± 31.2 N/m for baseline which declined to 159 ± 28.6 N/m after 24 h and recovered for 167 ± 31.1 N/m after 48 h. The WBC group showed a mean of 179 ± 31.9 N/m for baseline which deteriorated to 162 ± 29.1 N/m after 24 hours and recovered to 173.1 ± 30.6 N/ m after 48 h. The CWI group showed a similar pattern, 180 ± 26.8 N/m which declined to 164 ± 26.0 N/m after 24 h and increased to 175.8 ± 29.7 N/m after 48 h.

An ANOVA analysis of variance was conducted to see if significant differences existed among groups (Table 18).

Table 18– Leg Flexion: Data Differences

		Degrees of Freedom	F	Sig.
Baseline	Between Groups	2	0.02	0.97
	Within Groups	37		
	Total	39		
24 hours after exertion	Between Groups	2	0.09	0.90
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	0.28	0.75
	Within Groups	37		
	Total	39		

No statistical significant differences were found for all groups in any moment of evaluation.

5.3) Vertical Jumps

Jumping performance has been used extensively in physical assessment in sport. Squat jump and counter movement jump tests were conducted and followed the details described at section 4.3.2.

5.3.1) Squat Jump

Squat jump and its respective data may be found at Table 19.

Table 19 – Squat Jump Performance

		N	Mean	Std. Deviation	Minimum	Maximum
Baseline	Control	20	50.00	5.26	43.1	60.4
	WBC	10	51.62	7.66	37.6	60.7
	CWI	10	51.82	5.70	43	61.1
	Total	40	50.86	5.94	37.6	61.1
24 hours after exertion	Control	20	40.68	4.90	34.2	50.6
	WBC	10	46.58	8.31	31.2	57.2
	CWI	10	46.66	4.97	39.2	55.0
	Total	40	43.65	6.51	31.2	57.2
48 hours after exertion	Control	20	44.37	4.41	36.2	55.7
	WBC	10	50.41	8.22	35.3	60.2
	CWI	10	50.50	5.97	41.8	58.7
	Total	40	47.41	6.54	35.3	60.2

Values are expressed in centimeters (cm).

SJ performance decreased significantly after 24 h for all groups ($p < 0.05$). At 48 hours all groups tended to improve SJ performance.

For the control group, a decrease from the baseline of 50 ± 5.2 cm to 40.6 ± 4.9 cm was reported after 24 hours. At 48 hours, the performance increased to 44.3 ± 4.4 cm. The WBC group reported a mean of 46.5 ± 8.3 cm after 24 hours, less than the baseline of 51.6 ± 7.6 cm. After 48 hours, the WBC group was fully recovered. The CWI group reported a loss of from 51.8 ± 5.7 cm to 46.6 ± 4.9 cm after 24 h. At 48h the CWI group showed performances similar to baseline values.

An ANOVA analysis of variance was conducted to determine if any significant statistical differences were present among groups (Table 20).

Table 20 – Squat Jump: Data Differences

		Degrees of Freedom	F	Sig.
Baseline	Between Groups	2	0.40	0.66
	Within Groups	37		
	Total	39		
24 hours after exertion	Between Groups	2	5.00	0.01
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	5.25	0.01
	Within Groups	37		
	Total	39		

Before exertion, no group showed any significant statistical difference (F (2, 37) = 0.40, p = 0.66). After 24 h, data suggests that a significant statistical difference between groups was present (F (2, 37) = 5.00, p = 0.01). Likewise, after 48 hours a statistical significant difference was found among groups (F (2, 37) = 5.25, p = 0.01).

Since differences were found, a Bonferroni test was conducted to discern where the group differences lie (Table 21).

Table 21 – Squat Jump: Post Hoc Bonferroni 24h and 48h

	(A) Group	(B) Group	Mean Difference (A-B)	Sig.
24 hours after exertion	Control	WBC	-5.89	0.04
		CWI	-5.97	0.04
	WBC	Control	5.89	0.04
		CWI	-0.08	1
	CWI	Control	5.97	0.04
		WBC	0.08	1
48 hours after exertion	Control	WBC	-6.03	0.03
		CWI	-6.12	0.03
	WBC	Control	6.03	0.03
		CWI	-0.09	1
	CWI	Control	6.12	0.03
		WBC	0.09	1

At 24 h there was significant statistical differences between control and both CWI (p = 0.040) and WBC (p = 0.043). Similarly, at 48 hours, the control group had a statistically worse performance recovery when compared to both CWI (p = 0.034) and WBC (p = 0.037).

This means both CWI and WBC methods appear to enhance recovery for squat jump performances at 24h and 48 after exertion. However, no significant benefit was present by using one Cryotherapy method over the other (p = 1).

5.4.2) Counter-Movement Jump

Table 22 described the results of the Counter Movement Jump.

Table 22 – Counter Movement Jump Performance

		N	Mean	Std. Deviation	Minimum	Maximum
Baseline	Control	20	54.84	4.01	44.2	61.5
	WBC	10	57.31	4.92	48.1	64.2
	CWI	10	55.78	5.05	46.2	64.2
	Total	40	55.69	4.51	44.2	64.2
24 hours after exertion	Control	20	49.27	3.36	40.4	55.2
	WBC	10	52.87	5.98	44.7	62.1
	CWI	10	51.63	4.50	43.2	56.6
	Total	40	50.76	4.57	40.4	62.1
48 hours after exertion	Control	20	51.46	3.27	42.2	57.7
	WBC	10	54.76	4.44	45.9	61.8
	CWI	10	54.34	5.00	46.5	64
	Total	40	53.00	4.24	42.2	64

Values are expressed in centimeters (cm).

Table 22 shows that performance declined after 24 h, showing recovery at 48 h.

The control participants showed a decrease from an average of 54.8 ± 4 cm to 49.2 ± 3.3 cm at 24 hours. At 48 hours, their performance increased slightly to 51.4 ± 3.2 cm. The WBC participants showed a baseline of 57.3 ± 4.9 cm, which decreased to 52.8 ± 5.9 cm after 24 hours. It increased at 48 hours to 54.7 ± 4.4 cm. The CWI group showed a mean of 55.6 ± 5 cm at baseline. A decrease followed at 24 h (51.6 ± 4.5 cm) slightly increasing at 48 h (54.3 ± 5 cm).

The results showed that all groups followed the same behaviour pattern.

In order to discern if any significant statistical differences existed, an ANOVA analysis of variance was conducted (Table 23).

Table 23 – Counter Movement Jump: Data Differences

		Degree of Freedom	F	Sig.
Baseline	Between Groups	2	1	0.37
	Within Groups	37		
	Total	39		
24 hours after exertion	Between Groups	2	2.47	0.09
	Within Groups	37		
	Total	39		
48 hours after exertion	Between Groups	2	2.93	0.06
	Within Groups	37		
	Total	39		

At baseline, no significant differences were reported ($F(2, 37) = 1$, $p = 0.37$). At 24 hours after exertion, no statistical significant differences were found among the groups ($F(2, 37) = 2.47$, $p = 0.09$). Likewise at 48 hours, no significant differences were found ($F(2, 37) = 2.93$, $p = 0.06$).

6. Discussion

6.1) Perceived Discomfort

This study aimed to evaluate the efficacy of cryotherapy on the recovery process after an extremely exhaustive physical exertion. Performance indicators and perceived muscular discomfort were assessed 24 and 48 hours after exertion.

Perceived discomfort increased significantly at 24 and 48 hours for all groups. This reflects the aggressiveness of the fatigue protocol which induced a marked DOMS.

CWI and WBC treatments decreased significantly ($p < 0.05$) perceived discomfort in the quadriceps after 48 hours of recovery, when compared with PR. The other selected muscles showed no significant differences. These results are in line with previous research where CWI and WBC have been successfully proven on reducing perceptions of soreness, fatigue and tenderness after exercise (Eston & Peters, 1999; Bailey et al., 2007; Montgomery et al., 2008;Ingram et al., 2009; King & Duffield, 2009; Halson et al., 2008; Kinugasa & Kilding, 2009; Rowsell et al., 2009; Stacey et al., 2010; Rowsell et al., 2011, Versey et al., 2011; Ascensão et al., 2011; Hausswirth et al.,2011; Parouty et al., 2010; Roswell et al., 2011; Elias et al., 2012; Pointon et al., 2012). Specifically, Leeder et al. (2013) on the Meta-analysis conducted on CWI, report that cold water immersion had a moderate effect in alleviating DOMS after exercise and was highly effective in DOMS reduction following high intensity exercise at 24 and 48 hours. In our study, CWI was applied 30 minutes after exertion. Although, in the literature cryotherapy has been applied immediately after exertion, our results are similar to those found by other authors.

For CWI, Ascensão et al. (2011) shows improvement in perceived discomfort in CWI vs TWI at 24 hours at calf and quadriceps, with an acute CWI application of 10ºC for 10 minutes, however their exertion protocol is extremely different from ours.

For WBC, Sarabon et al. (2013) reports that participants after one 3 minute WBC session between -140ºC to -190ºC shows fatigue perception ratings lower from 1h till 72h at rest and during squat, compared with control conditions.

Hausswirth et al. (2011), also shows better ratings for fatigue and tiredness after WBC. These studies are in line with our results for WBC.

Controversially, Costello et al. (2012) used an eccentric fatigue protocol and reported no beneficial effects of WBC on discomfort or muscle recovery.

In our study we have found positive effects of WBC and CWI only 48 h after exertion. A possible explanation lies on the nature of the fatigue protocol and the level of the sample used. Our participants were highly trained, national ranked athletes with several years of experience in sport, so they are expected to have enhanced recovery capacities. Furthermore, the fatigue protocol gave higher emphasis to quadriceps mechanical stress, compared to other fatigue protocols showed in the literature.

Broatch, Petersen and Bishop (2014) highlighted the possibility of placebo effect on cryotherapy. They conducted an experiment to determine the importance of placebo effect on Cryotherapy (CWI). This study observed the physiological merit of CWI for recovery from high-intensity exercise by investigating if the placebo effect is responsible for any acute performance or psychological benefits. The fatigue method utilized was a high intensity interval session. Thirty males (30) performed 4 x 30s sprints, immediately followed by one of the following three 15-min recovery conditions: CWI (10ºC), thermoneutral water immersion with placebo (TWIP), or thermoneutral water immersion control (TWI). The authors concluded that a recovery placebo (TWIP) administered after an acute high-intensity interval training session is superior in the recovery of muscle strength over 48 hours compared with TWI and is as effective as CWI. The authors noted that it is probable that the subjective decreased in muscle soreness is partially due to the placebo effect.

Eventually, our positive results on quadriceps perceived discomfort can be due, also partially, to the placebo effect.

The studies still show conflict, however, some of the discrepancy could be addressed to the differences in the experimental designs.

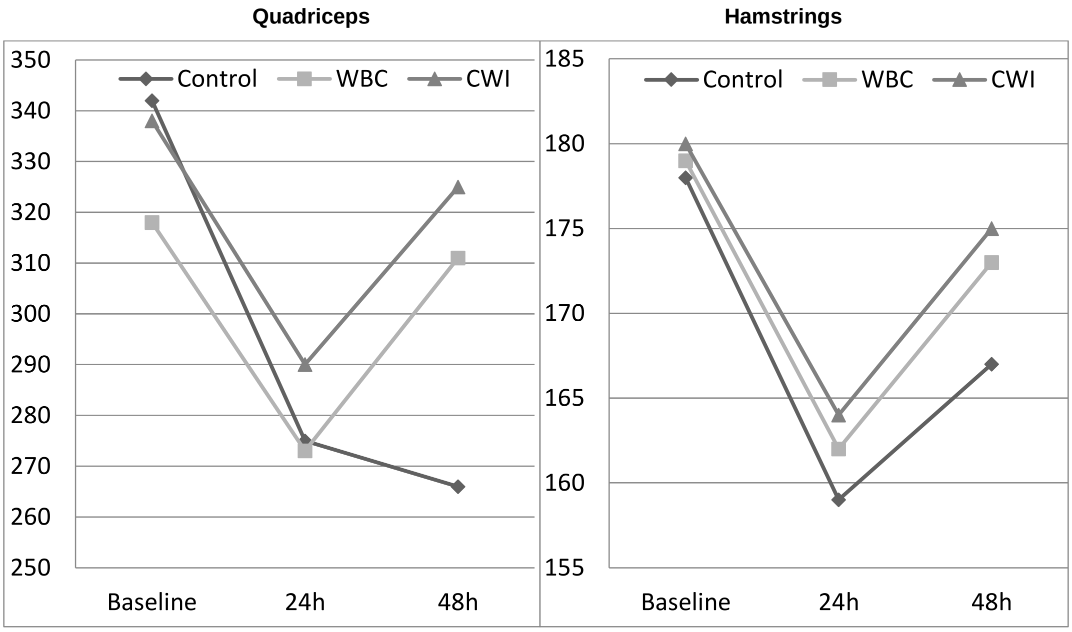
From our results, cryotherapy has a positive effect on the indexes of perceived muscle discomfort, at least, 48 h after exertion in muscle groups that have suffered dramatic mechanical stress. Further investigations can confirm this assumption.

6.2) Maximum Isometric Voluntary Contraction

Maximal strength has been used to assess Cryotherapy benefits in several studies, with mixed results. Several authors showed evidence for improved strength recovery (Bailey et al., 2007; Vaile et al., 2008; Ingram et al., 2009; Ascensão et al., 2011; Hausswirth et al., 2011; Pournot et al. 2011a; Fonda & Sarabon, 2013; Ferreira et al. 2015) while others report no benefit (Eston & Peters, 1999; Sellwood et al., 2007; Goodall & Howatson, 2008; Jakeman, Macrae & Eston, 2009; Rowsell et al., 2009; Costello et al., 2012).

In our study muscular performance for both exercises – leg extension and leg flexion, decreased after 24 h for all groups. All recovery methods showed similar effects at 24h. After 48 h of recovery, muscular and performance responses were conditioned by the recovery method and the muscle group selected. While Cryotherapy improved the recovery process for the quadriceps MIVC (leg extension) at 48 hours, no significant changes were seen at 24 h (Chart 1). For hamstrings MIVC, all the recovery methods showed similar results at 24 and 48 h after exertion (Chart 1). Both CWI and WBC methods showed similar benefits in the recovery process of quadriceps muscle performance.

Chart 1 – MIVC Quadriceps and MIVC Hamstrings: Overview



Values are means and expressed in Newton/meter.

Our results are in line with studies that report improved maximal strength at the 48 h. However, literature shows that benefits are evident usually as early as 1 to 24 h. Bailey et al. (2007) showed differences at both 24 and 48 hours for MIVC (Quadriceps and Hamstrings) between CWI and control groups. A more conflictual example is the study of Pournot et al. (2011a) which showed significant MVC improvement 1h and 24h after exertion.

Hausswirth et al. (2011) showed greater muscle strength after WBC, at as early as post-1 hour compared with the passive recovery group, whose strength was still suppressed.

Usually trained subjects recover faster than normal (Bailey et al., 2007; Hausswirth et al., 2011; Pournot et al. 2011a). As our participants are well trained athletes the differences must be searched in other reasons. A possible explanation for the results discrepancy between our study and others is the dramatic aggressiveness induced by our protocol.

Cryotherapy studies focused in strength recovery at 48 hours (Vaile et al., 2008; Ingram et al. 2009; Ferreira et al., 2015) closely resemble our study. Vaile et al. (2008), showed statistical significant differences in isometric squat at 48h and 72h in the CWI group versus control. Vaile et al. (2008) used multiple CWI sessions which do differ from our acute session. Albeit fatigue protocols have been quite different the results are similar to ours.

Ingram et al. (2009) reports leg strength (extension and flexion) values at 48 h after exertion, similar to baseline values (fully recovered) where significant differences still existed for control groups. The flexion results (hamstrings) do contradict our findings to some extent as they report an improvement at 48 hours. Once more the aggressiveness of our protocol can justify the differences.

Ferreira et al. (2015) utilized a maximal isometric peak torque of the right knee extensors measured by an Isokinetic Dynamometer. Results were favorable for an acute WBC exposure as it improved MIVC at 72 hours versus control whose strength performance was still suppressed at 96 hours. Ferreira et al. (2015) participants were not highly trained athletes so this might cause a "late" recovery. As we have seen before, trained subjects recover faster.

MIVC of the quadriceps had a higher rate of performance loss when compared with hamstrings which presented no significant differences among groups. Yet, this might still be explained if we consider the nature of the fatigue protocol as it heavily focuses on the quadriceps rather than on the hamstrings. Hamstrings have a supporting role during leg press, and it’s not surprising that the muscle damage was not as severe as in the quadriceps.

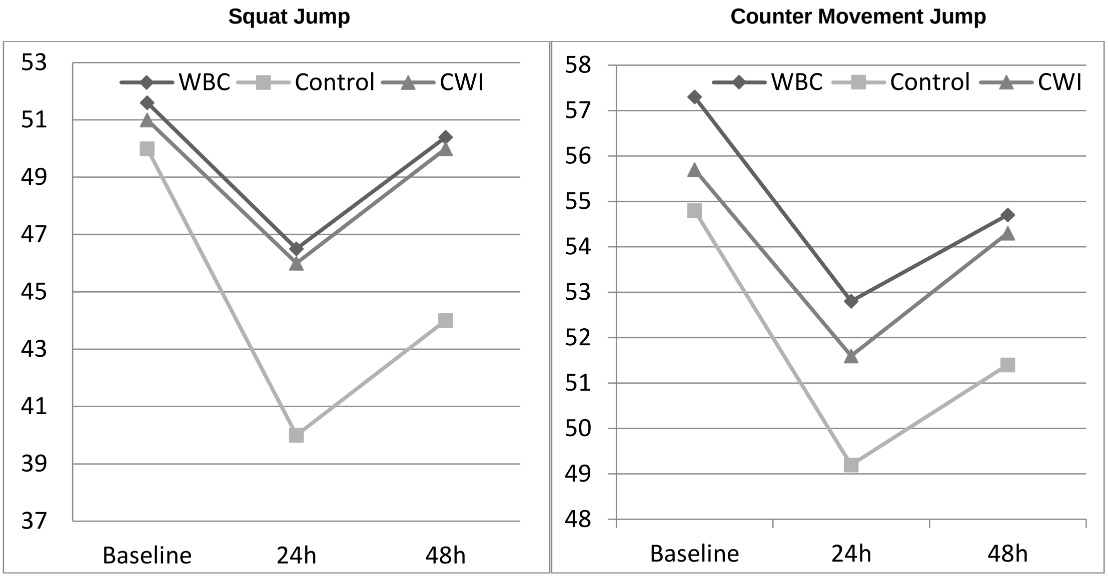
From our results the selected fatigue protocol was more aggressive for quadriceps than for hamstrings. This speculation is somewhat supported by the fact that all recovery methods showed similar results in performance testing. We can also speculate that the greater the muscle aggression the better the efficacy of the cryotherapy methods. It appears that hamstrings damage in our sample of highly trained participants is lower than quadriceps damage. This assumption open a field for biochemistry and muscle biopsy studies to confirm or infirm our results.

6.3) Squat Jump and Counter Movement Jump

Our results showed a significant performance decrease for all groups at 24h for both SJ and CMJ. This confirms the deleterious effect of the fatigue protocol on muscle performance.

SJ showed an improvement in performance at 24h and 48 h following CWI and WBC recovery methods, which differentiate clearly from the passive method. CMJ performances show no statistical significant differences among groups. However, it can be seen a trend for retarded recovery through the passive method. An overview of both tests is shown at Chart 2.

Chart 2 – Squat and Counter Movement Jump: Overview



Values are means and are expressed in Newton/meter.

We found no significant statistical differences between Cryotherapy methods, and we can state that CWI and WBC facilitated muscle performance recovery in similar manner.

Our findings are in line with results found in several studies where squat jump performances after exertion were better in groups who performed Cryotherapy (Vaile et al. 2008; Montgomery et al. 2008).

Specifically, Vaile et al. (2008) reported that compared to PR, change in max power performance (% change from baseline in squat jump) was significantly less at 48h ($p = 0.01$) and 72h ($p = 0.03$) post-exercise following CWI.

In our study, CMJ recovery differentiated clearly from SJ recovery. SJ showed significant performance changes at 24 and 48 hours after cryotherapy treatments, while CMJ showed no significant changes at 24 and 48 hours for all recovery treatments. Our findings are corroborated by Rowsell et al. (2009), who did not observe any recovery effect of CWI against decrements in repeated sprint and countermovement jump performances caused by soccer matches.

The differences between CMJ and SJ are probably due to the elastic proprieties of the muscle which are elicited in CMJ which attenuate muscle tension. Adding, SJ protocol determines that participants had to remain at 45º for 3 s what increases overall tension. For a subject suffering from severe discomfort (as was shown at discussion 6.1) increased initial tension in SJ could accentuate performance deterioration.

Some authors claim the higher specific sensitivity of more contractile-dependent muscular performance tests such as strength (MVIC) compared with more neuromuscular dependent abilities such as sprints or jumps (Warren et al., 1999; Bailey et al., 2007 as cited in Ascension et al., 2011). This lack of treatment efficacy against more neuromuscular abilities is discredited with the facilitated return of sprint performance in Ascensão et al. (2011); furthermore our SJ results don't support this theory.

Other authors contradict our results. White et al. (2014) claimed that a CWI intervention improved recovery for SSC abilities but not those who solely rely in concentric power. Bailey et al. (2007) also showed no statistical differences in SJ recovery after CWI. However, authors such as Pournot et al. (2011) showed improvement for CMJ and sprint abilities as early as 1h after exertion, in the group who had performed CWI.

Our results showed improvement on SJ performance at 24h and 48h for CWI and WBC groups, with no significant differences at any time point for CMJ. These results conflict with several studies found in the literature and suggest that further research is need with larger samples and other fatigue protocols.

7. Conclusions

The purpose of this study has been to assess if Cryotherapy (CWI or WBC) produces significant benefits on muscle performance during recovery after exhaustive exertion, compared with passive recovery.

- Jumping ability (SJ) recovery after exertion appears to have been enhanced by CWI or WBC treatments at 24h and 48h compared with PR.

- Muscle strength capability (leg extension) was enhanced with CWI and WBC treatments after 48 h of recovery. No differences were seen at 24 h among treatments.

- Pain perception remained mostly unchanged after 24 h. However, after 48 hours perception of discomfort of the quadriceps was lower in CWI and WBC groups compared with control. Other parameters show no significant differences among groups.

- CWI and WBC showed similar results in all selected parameters.

As corollary we can state that Cryotherapy is an adequate method to recover faster after exhaustive exercise.

7. Bibliography

Armstrong RB. Ogilvie RW. Scwane JA. (1983). Eccentric exercise-induced injury to rat skeletal muscle. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, 54(1):80-93.

Ascensão A., Leite M., A. N. Rebelo, Magalhães S. & Magalhães J. (2011). Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *Journal of Sports Sciences,* 29(3):217-225.

Babault, N., Desbrosses, K., Fabre, M. S., Michaut, A., & Pousson, M. (2006). Neuromuscular fatigue development during maximal concentric and isometric knee extensions. *Journal of Applied Physiology*, *100*(3), 780-785.

Bailey, D. M., Erith, S. J., Griffin, P. J., Dowson, A., Brewer, D. S., Gant, N., & Williams, C. (2007). Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *Journal of sports sciences*, *25*(11), 1163-1170.

Baltzopoulos, V., & Brodie, D. A. (1989). Isokinetic dynamometry. *Sports Medicine*, *8*(2):101-116.

Banfi, G., Lombardi, G., Colombini, A., & Melegati, G. (2010). Whole-body Cryotherapy in athletes. *Sports Medicine*, *40*(6), 509-517.

Bartlett, R. (1997). *Introduction to sports biomechanics*. Taylor & Francis.

Bleakley, C. M., Bieuzen, F., Davison, G. W., & Costello, J. T. (2014). Whole-body Cryotherapy: empirical evidence and theoretical perspectives. *Open access journal of sports medicine*, *5*, 25-36.

Bleakley, C. M., McDonough, S., Gardner, E., Baxter, D. G., Hopkins, T. J., Davison, G. W., & Costa, M. T. (2012). Cold-water immersion (Cryotherapy) for preventing and treating muscle soreness after exercise. *Sao Paulo Medical Journal*, *130*(5), 348-348.

Balsom, P. D., Gaitanos, G. C., Söderlund, K., & Ekblom, B. (1999). High-intensity exercise and muscle glycogen availability in humans. *Acta Physiologica Scandinavica*, *165 (4)*, 337-346.

Bishop, P. A., Jones, E., & Woods, A. K. (2008). Recovery from training: a brief review: brief review. *The Journal of Strength & Conditioning Research*, *22*(3), 1015-1024.

Borgmeyer, J. A., Scott, B. A., & Mayhew, J. L. (2010). The effects of ice massage on maximum isokinetic-torque production. *JSR*, *13*(1), 1-8

Broatch, J. R., Petersen, A., & Bishop, D. J. (2014). Post exercise cold-water immersion benefits are not greater than the placebo effect. *Medicine and Science in Sports & Exercise 46*(11), 2139-2147.

Brophy-Williams, N., Landers, G., & Wallman, K. (2011). Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance. *Journal of sports science & medicine*, *10*(4), 665.

Bulatova, M., & Platonov, V. N. (1998). Entrenamiento en condiciones extremas: altura, frío y variaciones horarias. *Paidotribo.*

Cairns, S. P. (2006). Lactic acid and exercise performance. *Sports Medicine*, *36*(4), 279-291.

Casey, A., Constantin-Teodosiu, D., Howell, S., Hultman, E., & Greenhaff, P. L. (1996). Metabolic response of type I and II muscle fibers during repeated bouts of maximal exercise in humans. *American Journal of Physiology-Endocrinology and Metabolism*, *271*(1), E38-E43.

Chapman, D., Newton, M., Sacco, P., & Nosaka, K. (2006). Greater muscle damage induced by fast versus slow velocity eccentric exercise*. International journal of sports medicine,* 27(8), 591-598.

Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed onset muscle soreness. *Sports Medicine*, *33*(2), 145-164.

Clarkson, P. M., & Hubal, M. J. (2002). Exercise-induced muscle damage in humans. *American journal of physical medicine & rehabilitation*, *81*(11), S52-S69.

Clarkson, P. M., & Sayers, S. P. (1999). Etiology of exercise-induced muscle damage. *Canadian journal of applied physiology*, *24*(3), 234-248.

Colliander, E. B., & Tesch, P. A. (1990). Effects of eccentric and concentric muscle actions in resistance training. *Acta physiologica scandinavica*, 140(1), 31-39.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International journal of sports physiology and performance*, *3*(2), 131.

Costello, J. T., Algar, L. A., & Donnelly, A. E. (2012). Effects of whole-body Cryotherapy (− 110° C) on proprioception and indices of muscle damage. *Scandinavian journal of medicine & science in sports*, *22*(2), 190-198.

Donatelli R, Wooden M. (1989). *Orthopedic Physical Therapy*. New York, NY: Churchill Livingstone Inc.;

Dugué, B., Smolander, J., Westerlund, T., Oksa, J., Nieminen, R., Moilanen, E., & Mikkelsson, M. (2005). Acute and long-term effects of winter swimming and whole-body Cryotherapy on plasma antioxidative capacity in healthy women. *Scandinavian journal of clinical & laboratory investigation*, *65*(5), 395-402.

Dutka, T. L., & Lamb, G. D. (2004). Effect of low cytoplasmic [ATP] on excitation–contraction coupling in fast-twitch muscle fibres of the rat. *The Journal of physiology*, *560*(2), 451-468.

Elias, G.P., M.C. Varley, V.L. Wyckelsma, R.J. Aughey, M.J. McKenna and C.L. Minahan, (2012). Effects of water immersion on post training recovery in Australian footballers. *International Journal Sports Physiology Performance*, 7(4): 357-366

Enoka, R. M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology*, *81*(6), 2339-2346.

Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *Journal of sports sciences*, *17*(3), 231-238.

Faulkner, J. A., Brooks, S. V., & Opiteck, J. A. (1993). Injury to skeletal muscle fibers during contractions: conditions of occurrence and prevention. *Physical therapy*, *73* (12), 911-921.

Ferreira-Junior, J. B., Bottaro, M., Loenneke, J. P., Vieira, A., Vieira, C. A., & Bemben, M. G. (2014). Could whole-body Cryotherapy (below− 100° C) improve muscle recovery from muscle damage? *Frontiers in physiology*, *5*, 247

.

Ferreira-Junior, J. B., Bottaro, M., Vieira, A., Siqueira, A. F., Vieira, C. A., Durigan, J. L. Q., & Bemben, M. G. (2015). One session of partial-body Cryotherapy (−110° C) improves muscle damage recovery. *Scandinavian Journal of Medicine & Science in Sports*.

Fonda, B., & Sarabon, N. (2013). Effects of whole-body Cryotherapy on recovery after hamstring damaging exercise: A crossover study. *Scandinavian journal of medicine & science in sports*, *23*(5), e270-e278.

Friden, A. (1981). Morphological study of delayed muscle soreness. *Experientia*, 37, 506-507

Friden J., Lieber, R., L. (1998). Segmental muscle fiber lesions after repetitive eccentric contractions. *Cell Tissue Research*, 293, 65-171

Gibson, A. S. C., Lambert, M. I., & Noakes, T. D. (2001). Neural control of force output during maximal and submaximal exercise. *Sports Medicine*, *31*(9), 637-650.

Goodall, S., & Howatson, G. (2008). The effects of multiple cold water immersions on indices of muscle damage. *Journal of sports science & medicine*, *7*(2), 235.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery. *International Journal Sports Physiology and Performance*, *6*(2), 147-159.

Halson, S., M. Quod, D. Martin, A. Gardner, T. Ebert and P. Laursen, (2008). Physiological responses to cold water immersion following cycling in the heat. *International Journal Sports Physiology and Performance*, 3(3), 331-346

Hausswirth C, Louis J, Bieuzen F, Pournot H, Fournier J, et al. (2011) Effects of Whole-Body Cryotherapy vs. Far-Infrared vs. Passive Modalities on Recovery from Exercise-Induced Muscle Damage in Highly-Trained Runners*. PLOS ONE* 6(12), e27749.

Hislop, H. J., Perrine, J. J. (1967). The isokinetic concept of exercise. *Physical Therapy,* 47 (2), 114-117.

Hom, C., Vasquez, P., Pozos, R.S. (2004). Peripheral skin temperature effects on muscle oxygen levels. *Journal of Thermal Biology*, 29, 785-789

Howatson, G., Goodall, S., & Van Someren, K. A. (2009). The influence of cold water immersions on adaptation following a single bout of damaging exercise. *European Journal of Applied Physiology*, *105*(4), 615-621.

Howatson, G., Van Someren, K., & Hortobagyi, T. (2007). Repeated bout effect after maximal eccentric exercise. *International Journal of Sports Medicine*, *28*(7), 557-563.

Howatson, G., & Van Someren, K. A. (2008). The prevention and treatment of exercise-induced muscle damage. *Sports Medicine*, *38*(6), 483-503.

Huskisson, E. C. (1974). Measurement of pain. *The Lancet*, *304*(7889), 1127-1131.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science and Medicine in Sport*, *12*(3), 417-421.

Jakeman, J. R., Macrae, R., & Eston, R. (2009). A single 10-min bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics*, *52*(4), 456-460.

Kinugasa, T., & Kilding, A. E. (2009). A comparison of postmatch recovery strategies in youth soccer players. *Journal of Strength and Conditioning* Research, 23 (5), 1402–1407.

Klavora, P. (2000). Vertical-jump tests: a critical review. *Strength & Conditioning Journal*, *22*(5), 70.

Knuttgen, H. and Kraemer, W. (1987) Terminology and measurements in exercise performance. *Journal of Applied Sports Science Research,* 1, 1-10

Komi, P. V. (Ed.). (1993). *Strength and power in sport*. Blackwell scientific publications.

Kuligowski, L. A., Lephart, S. M., Giannantonio, F. P., & Blanc, R. O. (1998). Effect of whirlpool therapy on the signs and symptoms of delayed-onset muscle soreness. *Journal of Athletic Training*, *33*(3), 222.

Leeder, J., C. Gissane, K.V. Someren, W. Gregson and G. Howatson (2013). Cold-water immersion and recovery from strenuous exercise: A meta-analysis. *British Journal of Sports Medicine*, 46(4): 233-240.

Lindstedt, S. L., LaStayo, P. C., & Reich, T. E. (2001). When active muscles lengthen: properties and consequences of eccentric contractions. *Physiology, 16*(6), 256-261.

Linnamo, V., Bottas, R., & Komi, P. V. (2000). Force and EMG power spectrum during and after eccentric and concentric fatigue. *Journal of electromyography and Kinesiology*, *10*(5), 293-300.

McGinley C, Shafat A, Donnelly AE. (2009). Does antioxidant vitamin supplementation protect against muscle damage? *Sports Medicine* 39 (12), 1011–1032.

Moffroid, M., Whipple, R., Hofkosh, J., Lowman, E. and Thirtle, H., (1969). A study of isokinetic exercise. *Physical Therapy,* 49(7), 735-747.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences*, *26*(11), 1135-1145.

Moopanar, T. R., & Allen, D. G. (2005). Reactive oxygen species reduce myofibrillar Ca2+ sensitivity in fatiguing mouse skeletal muscle at 37 C. *The Journal of physiology*, *564*(1), 189-199.

Morgan, D. L., & Allen, D. G. (1999). Early events in stretch-induced muscle damage. *Journal of Applied Physiology*, *87*(6), 2007-2015.

Nikolaidis MG, Kyparos A, Spanou C, Paschalis V, Theodorou AA, Vrabas IS (2012). Redox biology of exercise: an integrative and comparative consideration of some overlooked issues. *Journal of Experimental Biology,* 215 (10), 1615–25.

Noreau, L., & Vachon, J. (1998). Comparison of three methods to assess muscular strength in individuals with spinal cord injury. *Spinal cord*, *36*(10), 716-723.

Parouty, J., Al Haddad, H., Quod, M., Leprêtre, P. M., Ahmaidi, S., & Buchheit, M. (2010). Effect of cold water immersion on 100-m sprint performance in well-trained swimmers. *European Journal of Applied Physiology*, *109*(3), 483-490.

Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P. B. (2010). Effect of a 5-min cold-water immersion recovery on exercise performance in the heat. *British Journal of Sports Medicine*, *44*(6), 461-465.

Perrin, D. H. (1986). Reliability of isokinetic measures. *Athletic training*, *21 (3),* 319-321.

Perrin, D. H., & Costill, D. L. (1993). Isokinetic exercise and assessment. *Human Kinetics Publishers*, 2

Pincivero DM, Lephart SM, Karunakara RA (1996). Reliability and precision of isokinetic strength and muscular endurance for the quadriceps and hamstrings. *International Journal of Sports Medicine*, 18 (2), 113-117.

Pointon, M., R. Duffield, J. Cannon and F.E. Marino, (2012). Cold-water immersion recovery following intermittent-sprint exercise in the heat. *European Journal Applied Physiology*, 112(7): 2483-2494.

Pournot, H., Bieuzen, F., Duffield, R., Lepretre, P. M., Cozzolino, C., & Hausswirth, C. (2011a). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *European Journal of Applied Physiology*, *111*(7), 1287-1295.

Pournot, H., Bieuzen, F., Louis, J., Fillard, J. R., Barbiche, E., & Hausswirth, C. (2011b). Time-course of changes in inflammatory response after whole-body Cryotherapy multi exposures following severe exercise. *PLOS ONE*, *6*(7), e22748.

Proske, U., & Allen, T. J. (2005). Damage to skeletal muscle from eccentric exercise. *Exercise and sport sciences reviews*, *33*(2), 98-104.

Proske, U., & Morgan, D. L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology*, *537*(2), 333-345.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences*, *27*(6), 565-573.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal of Sports Sciences*, *29*(1), 1-6.

Rubley, M. D., Denegar, C. R., Buckley, W. E., & Newell, K. M. (2003). Cryotherapy, sensation, and isometric-force variability. *Journal of Athletic Training*, *38*(2), 113.

Sahlin, K. (1985). Muscle fatigue and lactic acid accumulation. *Acta Physiologica Scandinavica. Supplementum*, *556*, 83-91.

Sahlin, K. (1992). Metabolic factors in fatigue. *Sports Medicine*, *13*(2), 99-107.

Sahlin, K., Tonkonogi, M., & Söderlund, K. (1998). Energy supply and muscle fatigue in humans. *Acta Physiologica Scandinavica*, *162*(3), 261-266.

Sarabon, N., Panjan, A., Rosker, J., & Fonda, B. (2013). Functional and Neuromuscular Changes in the Hamstrings after Drop Jumps and Leg Curls. *Journal of Sports Science & Medicine*, *12*(3), 431.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: a randomized controlled trial. *British Journal of Sports Medicine*, *41*(6), 392-397.

Sesto, M. E., Chourasia, A. O., Block, W. F., & Radwin, R. G. (2008). Mechanical and magnetic resonance imaging changes following eccentric or concentric exertions. *Clinical Biomechanics*, *23*(7), 961-968.

Silva, F. (2013). Influência da crioterapia no tendão quadricipital na força máxima, na sensação de força produzida e na funcionalidade do membro inferior. *Repositório Cientifico do Instituto Politécnico do Porto.*

Stacey, D. L., Gibala, M. J., Martin Ginis, K. A., & Timmons, B. W. (2010). Effects of recovery method after exercise on performance, immune changes, and psychological outcomes. *Journal of Orthopedic and Sports Physical Therapy*, *40*(10), 656-665

Thistle, H. G., Hislop, H. J., Moffroid, M. and Lowman, E. W., (*1966).* Isokinetic contraction: a new concept of resistive exercise. *Archives of Physical Medicine and Rehabilitation,* 48, 279-282.

Thornley, L.J., Maxwell, N.S., Cheung, S.S. (2003). Local tissue temperature effects on peak torque and muscular endurance during isometric knee extension. *European Journal of Applied Physiology*. 90 (5), 588-94.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness. *European Journal of Applied Physiology*, *102*(4), 447-455.

Versey, N. G., Halson, S. L., & Dawson, B. T. (2013). Water immersion recovery for athletes: effect on exercise performance and practical recommendations. *Sports Medicine,* 43 (11), 1101-1130.

Weineck, J., Carvalho, B. M. R., & Barbanti, V. J. (1999). Treinamento ideal: instruções técnicas sobre o desempenho fisiológico, incluindo considerações específicas de treinamento infantil e juvenil*. Manole.*

Wilcock, I. M., Cronin, J. B., & Hing, W. A. (2006). Water immersion: does it enhance recovery from exercise?. *International Journal of Sports Physiology and Performance*, *1*(3), 195.

White G.E.**,** Rhind S.G., Wells G.D. (2014). The effect of various cold-water immersion protocols on exercise-induced induces inflammatory response and functional recovery from high-intensity sprint exercise. *European Journal of Applied Physiology,* 114 (11), 2353-2367.