Universitat de Lleida

Physiological Effects ot the cool vest jacket as a recovery method in soccer

Efectes fisiològics de la jaqueta refrigerant com a mètode de recuperació en futbol

Carles Lorente i González

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Universitat de Lleida

TESI DOCTORAL

Physiological effects of the Cool Vest Jacket as a recovery method in soccer

Efectes Fisiològics de la Jaqueta Refrigerant com a mètode de recuperació en futbol

Carles Lorente i González

Memòria presentada per optar al grau de
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Dr. Francisco Corbi i Soler

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> *"Cuando bebas agua,*
> *recuerda la Fuente"*
> *(proverbi xinès)*

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
ANOVA	Analysis of Variance
ATP	Adenosin Triphospate
ATP-PCr	Phosphocreatine
BF	Biceps Femoris
Ca^{2+}	Calcium Ions
CG	Control Group
CI	Confidence Interval
CMJ	Counter Movement Jump
CVG	Cool Vest Group
CVJ	Cool Vest Jacket
Dm	Maximal Displacement Amplitude
DOMS	Delayed Onset Muscle Soreness
DVJ	Drop Vertical Jump
FIFA	Fédération Internationale de Football Association
FPPA	Frontal Plane Projection Angle
H^+	Hydron (Proton)
HRR	Heart Rate Recovery
IC	Initial Contact
ICC	Intraclass Correlation Coefficient
ICool	Internal Cooling
K^+	Potassium Ion
LAC	Blood Lactate Concentration
LC	Local Cooling
mA	Milliampers
MAX	Peak Knee Flexion

mL/kg/min	Millilitres Of Oxygen Per Kilogram Of Body Mass Per Minute
$Mmol{\cdot}l^{-1}$	Millimols Per Liter
NA^+	Sodium
PCO_2	Partial Pressure of Carbon Dioxide
RPE	Rate Of Perceived Exertion
RSSA	Repeated Shuttle Sprint Ability
SD	Standard Deviation
SkBF	Skin Blood Flow
St	Sustain Time
Tc	Core Temperature
Tc	Contraction Time
Td	Delay Time
TMG	Tensiomyography
Tr	Half Relaxation Time
TRH	Thyrotropin Releasing Hormone
Ts	Skin Temperature
TSH	Thyroid Stimulating Hormone
Tt	Tympanic Temperature
Vc	Velocity Of Mean Contraction
Vd	Velocity Of Muscle Deformation
VO_2 max	Maximal Oxygen Uptake
WBC	Whole Body Cryotherapy
WBCool	Whole Body Cooling

RESUM

Un dels motius de l'increment de la fatiga durant exercicis d'alta intensitat és l'augment de la temperatura corporal. Aquest augment afecta a la capacitat de dissipar la calor induïda per l'exercici i/o per l'entorn i pot afectar també al nivell muscular de manera que la capacitat de contracció es vegi reduïda. Elements com la jaqueta refrigerant poden ajudar a reduir la temperatura en esportistes amb hipertèrmia i accelerar la recuperació.

Aquesta tesi doctoral es basa en l'aplicació de la jaqueta refrigerant durant 15 minuts (el temps de descans durant la mitja part d'un partit de futbol) després de dos diferents protocols de fatiga, un en normotèrmia (22°C) i l'altre en condicions de calor (33°C) per comprovar quines són les respostes fisiològiques i de rendiment a nivell neuromuscular i cinemàtic.

En els diferents estudis duts a terme durant aquesta tesi, es van estudiar habilitats pròpies del futbol, que s'ha demostrat que es veuen reduïdes degut a l'aparició de fatiga, com són els esprints, salts i xuts. També s'ha analitzat la prevenció de lesions, a nivell cinemàtic avaluant la sol·licitació lligamentosa durant la caiguda d'un salt i les propietats de contracció del bíceps femoral amb tensiomiografia. A més, es va investigar la recuperació a nivell fisiològic en condicions de calor, l'efecte en la freqüència cardíaca de recuperació i la concentració de lactat en sang.

En els diferents estudis es demostra com la jaqueta refrigerant ajuda a reduir la temperatura de la pell després dels dos protocols de fatiga i no provoca cap reducció de rendiment després de la seva aplicació. Així doncs, l'esportista es capaç de començar la següent sèrie d'activitat física amb un valors neuromusculars i fisiològics semblants als de l'inici de l'activitat, comparat amb els participants que no van dur la jaqueta refrigerant durant el període de descans, que mostren reduccions en algunes de les habilitats valorades.

RESUMEN

Uno de los motivos del incremento de la fatiga durante el ejercicio de alta intensidad es el aumento de la temperatura corporal. Este aumento afecta a la capacidad de disipar el calor inducido por el ejercicio y/o el entorno, afectando también a nivel muscular reduciendo la capacidad de contracción. Elementos como la chaqueta refrigerante pueden ayudar a reducir la temperatura en deportistas con hipertermia y acelerar la recuperación.

Esta tesis doctoral se base en la aplicación de la chaqueta refrigerante durante 15 minutos (el tiempo de descanso de la media parte de un partido de futbol) después de dos tipos distintos de protocolo de fatiga, uno en normotermia (22°C) y el otro en condiciones de calor (33°C) para comprobar cuáles son las respuestas fisiológicas y de rendimiento a nivel neuromuscular y cinemático.

En los distintos estudios realizados durante esta tesis se analizaron habilidades propias del futbol, que se ha demostrado que se reducen debido a la aparición de fatiga, tales como los esprints, saltos i chutes. También se analizó la solicitación ligamentosa durante la caída de un salto i las propiedades de contracción del bíceps femoral con tensiomiografía. Además, se investigó la recuperación a nivel fisiológico en condiciones de calor, el efecto en la frecuencia cardíaca de recuperación y la concentración de lactato en sangre.

En esta tesis se demuestra como la chaqueta refrigerante ayuda a reducir la temperatura de la piel después de los dos protocolos de fatiga y no provoca ninguna reducción de rendimiento después de su aplicación. El deportista es capaz de empezar la actividad física con unos valores neuromusculares y fisiológicos parecidos a los del inicio de la actividad, mientras que los participantes que no usaron la chaqueta refrigerante durante el periodo de descanso mostraron reducciones en el rendimiento de algunas de las habilidades valoradas.

ABSTRACT

One of the causes of fatigue during high intensity exercise is the rise of body temperature. This increment affects the capacity to dissipate heat induced by either exercise or environment and may also affect muscle contractibility, reducing its capacity. Tools such as a cool vest jacket may help reduce body temperature in hyperthermic athletes and accelerate recovery.

This doctoral thesis is based on the application of a cool vest jacket during 15 minutes (same time of a soccer half time) after two different fatigue protocols, one in normothermia (22°C) and another under hot conditions (33°C) and assess the physiological and performance responses in kinematics and neuromuscular function.

During the different studies carried out in this thesis, specific soccer properties, that have been demonstrated to be reduced with fatigue, such as sprints, jumps and kicks were analyzed. Injury prevention was also analyzed, assessing the kinematics of a jump landing and the muscle contractile properties of the biceps femoris with tensiomyography. Also, physiological properties under hot conditions such as the effect on heart rate recovery and blood lactate concentration were determined.

In this thesis, we demonstrate that the cool vest jacket significantly attenuates and reduces the skin temperature after two fatigue protocols and doesn't induce in any type of performance decrement after its application. The athlete is able to start the following bout of exercise with similar baseline neuromuscular and physiological values, while as those who didn't rest with the cool vest jacket during the study showed performance reductions in some of the abilities assessed.

Chapter 1

Introduction

1.1 Overture

Team sports athletes experience different levels of acute and accumulated fatigue during intense training and competition. The capacity to delay fatigue is one of the main issues for all coaches and fitness trainers. Team sports such as soccer, basketball or hockey (amongst others), are characterized by a larger number of high intensity actions during the game that may change the course of the game and the result (Radman et al., 2016; Rattray et al., 2015; Thomas et al., 2017). Meanwhile, the capacity to perceive and tolerate this fatigue throughout the game are mainly depending on individual capacities and fitness levels. One of the physiological focus as technical staff in any sport has to be the artificial speeding of the regenerative processes via recovery strategies to ensure the athletes are ready for the next bout of exercise or half of the game (Al-Nawaiseh et al., 2016; P. A. Bishop et al., 2008; Minett et al., 2014; Peiffer et al., 2010).

The accumulated fatigue within a practice session or a game has a direct effect on subsequent performance, reducing the capacity of the athlete to complete high intensity actions, such as sprints or jumps, and therefore the capacity to exert maximal muscle force or power (Mohr et al., 2005; Nybo & Nielsen, 2001; Rahnama et al., 2003).

Some physiological strains have been indicated as the cause of this ongoing fatigue. This fatigue can be classified as central, when the origin is driven neutrally, or from the brain and peripheral when it comes from skeletal muscle and neuromuscular junctions (Ament et al., 2009; Mohr et al., 2005). Although it is not clear which one creates a greater strain on the body, it has always been attributed peripherally to a metabolic capacity. Lowered phosphocreatine concentrations and depletion of muscle glycogen concentrations thus reduced glycolytic regeneration of ATP and increasing H^+ accumulations. Although the role of the brain and the Central Nervous System (CNS) has been acknowledged as an exercise regulator, altering cardiovascular, metabolic and thermal responses while exercising under fatigue conditions (Adams et al., 2016; Minett et al., 2014).

The ability to enhance recovery after an intense bout of exercise is widely studied and practiced, especially by professional athletes, trying to find a competitive edge to ensure the maximal performance for the next practice session or even the next exercise bout. Nutritional strategies, hydration, cool water immersion, sleeping, active recovery, stretching, compression garments, massage and electrical stimulation are the most common recovery strategies in a team sport such as soccer (Nedelec et al., 2015; Nedelec et al., 2013).

We decided to focus this doctoral thesis in one of these recovery methods, trying to discover if the use between bouts of exercise of halves in a game has any positive result in performance and may enhance a physiological recovery, which might have a positive result on performance.

Cooling is one of the recovery strategies used in sports to attenuate the increment of body temperature and reduce a possible environmental heat stress during exercise. Because recovery between bouts is often a short period of time, the cooling method to use had to be easy to apply, light for the athlete to move with, and inexpensive in case we are using this method for a team sport. We found the cool vest jacket one of the most suitable methods for this purpose, that has already been widely used as a precooling (Azad et al., 2016; C. C. Bongers et al., 2015; James et al., 2015) and postcooling (C. C. W. G. Bongers et al., 2017; Ihsan et al., 2016; Luhring et al., 2016) method in sports, but, as far as we know, not many studies have studied its effects in midcooling with a short recovery time.

Although its effects on endurance exercise have already been studied showing positive benefits after precooling, as far as we know there aren't midcooling studies trying to demonstrate the effects of wearing a cool vest jacket during the halftime of a soccer game on specific soccer skills, high intensity actions and related muscle contractibility.

This doctoral thesis is structured in nine chapters and three different parts. The current introduction, a basic review of thermoregulation, thermoregulation in exercise and under hot and cold conditions, and a review of cooling methods and strategies to enhance performance in sports to finally describe the three cooling enhancing strategies most commonly used before, during and between bouts of exercise (precooling, percooling and midcooling). Following this, the next chapter contains the general and specific objectives of this thesis.

The second part of this thesis, chapters 3 to 7, are the studies trying to find out the effectiveness of the cool vest jacket under normothermic conditions (3 to 6,) and under hot thermal environmental stress (7) in specific soccer abilities such as jumping, sprinting and ball kicking, in muscle fatigue contractibility and landing kinematics.

The chapters 8 and 9 are a general discussion, reviewing in deep all the studies and possible applications as well as the final conclusions of this doctoral thesis.

1.2 Thermoregulation

The regulation of temperature is the ability that a biological organism has to modify its temperature within certain boundaries, even when the surrounding temperature is different than the range of temperature that the body expects to work optimally. Living creatures can be classified by two different ways to obtain and create heat, Endothermically and Ectothermically (Boulant, 1998; Boyles et al., 2011; Havenith, 2001). Ectotherms species, also called cold-blooded, are the organisms that depend on an external source of heat to regulate their body temperature, because their physiologic sources of heat can't produce enough to control body temperature, thus relying on environmental heat sources. Meanwhile, endothermic species tend to maintain a constant body temperature independent from the environment (W Larry Kenney et al., 2015).

The human race, as an endothermic species (classically called homeothermic), can keep the core temperature almost constant within a narrow range, independently from environmental changes. Instead, our temperature may vary from one day to another, or even in a matter of few hours. The core temperature fluctuates by about 0.6°C and is lowest around 3 a.m., and highest around 6 p.m (Reilly et al., 2009; Waterhouse et al., 2005). Body temperature is kept constant due to a laborious balance between heat loss and production. The rate of heat production, thermogenesis, is balanced by the rate of dissipated heat to the environment, thermolisis. In a state of imbalance between thermogenesis and thermolisis, a change in the rate of heat body storage is produced and, consequently, a modification in the content of heat in the body and the core temperature (N. A. Taylor et al., 2008; Werner et al., 2008). Every time this balance is altered our body temperature changes, either rising or lowering. This process of thermal equilibrium is one of the many aspects for homeostasis of a body.

The main center in charge of the body's thermal control is located in the hypothalamus. Receiving information from cold and warm peripheral thermoreceptors located in the skin, central thermoreceptors situated in big vases, abdominal viscera and spine, and the blood prefunding the hypothalamus

(Hensel, 1981; Parsons, 2014). The hypothalamus maintains core temperature in the vital range by initiating the appropriate heat-producing or heat-loss reflex mechanisms and comparing the actual core temperature with the set-point value (Fig. 1). The medial preoptic nucleus and the anterior hypothalamic nucleus from the medial anterior region of the hypothalamus create a response to counteract the effects of a rise in the body's temperature activating cooling methods. (Boulant, 1998, 2000). When body temperature increases above normal and the homeostatics agents aren't able to maintain regular temperature, the body enters in a state known as hyperthermia. When central temperature is rising, then the thermoregulatory center activates the efferent fibers of the autonomic nervous system that increases heat loss producing cutaneous vasodilation and an increment of sweating (Shibasaki et al., 2010; Tansey et al., 2015).

In the opposite situation, we find a hypothermic condition when the body temperature decreases below normal levels (Castellani et al., 1999; McKemy, 2005; Parsons, 2014). The medial posterior nucleus of the hypothalamus reacts, reducing the heat loss throughout cutaneous vasoconstriction and reduction of sweating. Furthermore, if the temperature is lowered below normal levels, the hypothalamus increases heat production and intensifies muscular activity (enlarging muscle tone and shivering) (Fig. 1).

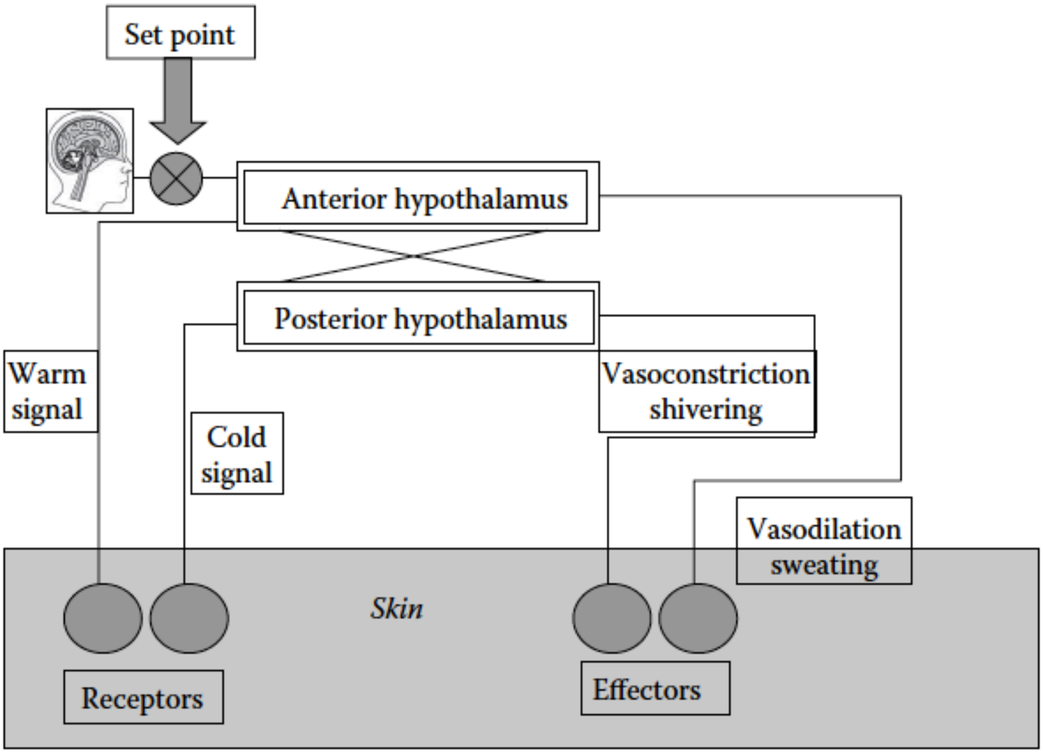


Figure 1. Simplified diagram of the thermoregulatory system. The displacement of the brain temperature above the set point results in vasodilation and sweating; a reduction in the skin temperature produces vasoconstriction and shivering. There are crossed inhibitory connections between the warm and cold systems (Extracted from Parsons (2014) Modified from McIntyre, D.A., Indoor Climate, Applied Science, London, 1980.)

1.3 Heat Regulation Mechanisms

Heat exchange between the body and the environment is continuous throughout the day, even if there aren't any thermal stress factors, with the hypothalamus balancing between heat production and heat loss with the objective of achieving thermal balance. These processes consist on bi-directional routes: convection, conduction, and radiation and two unidirectional routes: metabolic heat that increases the thermal load and evaporation with the objective of decreasing thermal load (Kenefick et al., 2007; Tansey et al., 2015). The standard heat balance equation where all avenues of heat gain and loss are represented is:

$$S = M \pm W \pm (R+C) - E$$

Where S is the rate of body heat storage, M is the rate of metabolic energy (heat) production, W represents mechanical work, R + C is the rate of radiant and convective energy exchanges, M is metabolic heat, R is radiation and E is rate of evaporative loss (Marino, 2008). The sum of these represents heat gain if positive and loss if negative, hence, if body temperature is increased or decreased.

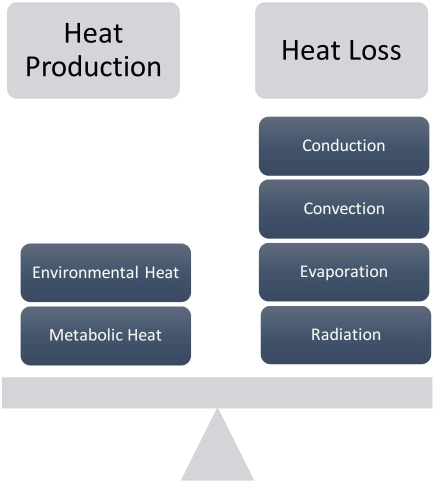


Figure 2. Balance factors between heat generated and heat loss evaporation (Extracted and adapted from (W. Larry Kenney et al., 2012)

1.3.1 Heat Exchange Mechanisms

Heat exchange mechanisms prevent the reaching of an excessive high core temperature, which might damage the body. With a greater body temperature, the hypothalamic heat producing processes are inhibited activating the heat-loss mechanisms (Fig 2).

Conduction

Heat conduction imply the transference of heat from and object to another through direct contact. It has a minimal effect on body heat transfer because it depends on the contact between skin and a cooler object. Despite this, it can be used as a cooling method by immersion in water to either cool or warm the body (Kenny et al., 2010; Parsons, 2014).

Convection

Convection is the transference of heat from one place to another by the movement of a gas or a liquid through a warm surface. In the human body, the circulatory system is responsible for transferring heat from active and working muscles to the skin surface. The air around the body is in constant motion and acts by removing the molecules of air warmed by skin contact. The larger the air or liquid movement, the higher the rate in which convective heat is eliminated (W Larry Kenney et al., 2015).

Conduction and convection are constantly removing body heat when the environmental temperature is lower than skin temperature. Although, when in hot temperatures, convection and conduction might cause a heat gain.

Radiation

Radiation is the body's main heat loss method. Body heat is liberated by emitting thermal radiation as infrared waves in all directions towards all objects surrounding it such as clothes, furniture, walls, etc. When the surroundings are cooler than the body, net radiative loss occurs. At around 21-25°C the human body releases around 60% of its excess heat via radiation (Davis et al., 2016; Yeargin, Casa, Armstrong, et al., 2006).

Evaporation

Evaporation is the most important way to dissipate heat during exercise and in warm environments. It represents around 80% of the total amount of heat loss when physically active and an environmental temperature above 20°C, although it's only 20% loss at rest. Because water absorbs a great deal of heat before vaporizing, its evaporation from the body surfaces removes a large amount of body heat. The water lost by evaporation reaches the skin surface by diffusion and through neuroactive sweat glands (Fig. 3). The evaporative rate is determined by air velocity and the water vapor pressure gradient between the skin and the environment. Although high relative humidity may limit sweat evaporation, it still plays one of the most important roles in dissipating heat during exercise (Shibasaki et al., 2010; Shibasaki et al., 2006).

Table 1. Estimated heat loss at rest and during exercise at 70% VO_2 max (W. Larry Kenney et al., 2012)

Mechanism of heat loss	Rest		Exercise	
	% Total	Kcal/min	% Total	Kcal/min
Conduction and Convection	20	0.3	15	2.2
Radiation	60	0.9	5	0.8
Evaporation	20	0.3	80	12.0

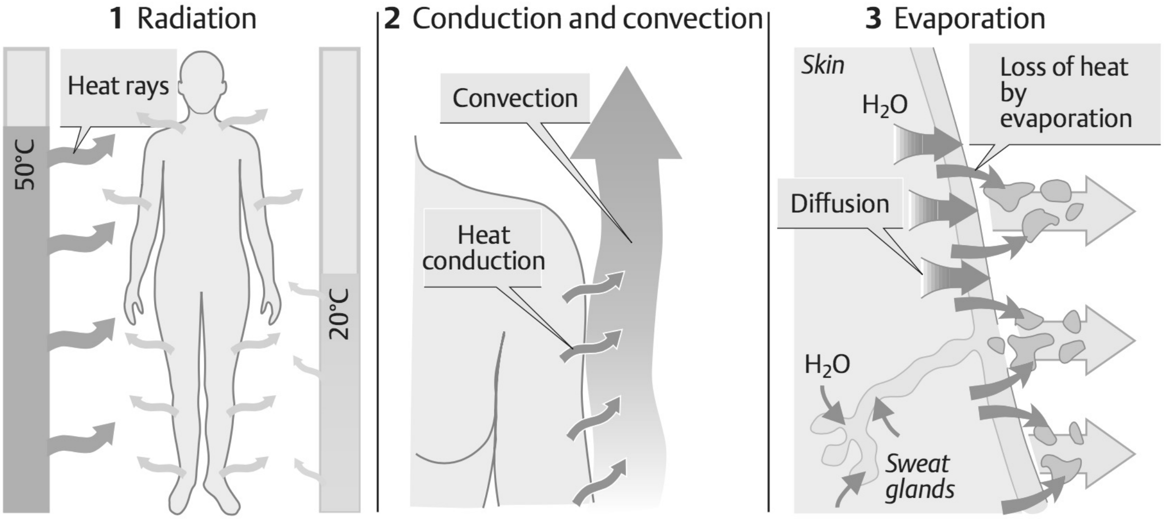


Figure 3. Heat Loss Mechanisms, extracted from Silbernagl et al. (2015)

1.4 Thermal Regulation Responses

The warm or cold types of thermoreceptors located peripherally throughout the skin and the internal receptors provide information to the hypothalamus to adjust the physiological responses to recover the thermal balance of the body. When temperatures detected are above or below the “set-point” levels, endocrine production initiates control mechanisms to increase or decrease energy production or dissipation to recover the baseline or set point temperature level (Parsons, 2014).

1.4.1 Heat Loss Mechanisms. Physiological Responses to an Increment of Body Temperature

Sweating

Sweating is activated by sympathetic fibers and secreted by eccrine sweat glands. Evaporation takes part through the sweat pores onto the surface of the skin, causing an evaporative cooling (Davis et al., 2016; Flouris et al., 2015).

Vasodilation of cutaneous blood vessels

Inhibiting the vasomotor fibers serving blood vessels of the skin allows the vessels to dilate. Muscle walls of the arterioles allow increased blood flow through the artery, redirecting blood into the superficial capillaries in the skin and increasing heat loss by radiation, convection and conduction (Gonzalez-Alonso, 2012; Tansey et al., 2015; Wendt et al., 2007).

1.4.2 Heat Production Mechanisms. Physiological Responses to A Reduction of Body Temperature

Metabolic Heat Production

The transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities are the sum of the biochemical processes that add thermal stress to the body. Metabolic heat production consists of two components: metabolic energy expenditure and external work. All reactions taking place in the body require energy (Gonzalez-Alonso, 2012; Havenith, 2001). These reactions are fueled by extracting oxygen from inhaled air and carbohydrates, fat and proteins ingested. The energy from these metabolic reactions is available to use towards mechanical work (Fig. 4). Nevertheless, most of these reactions are inefficient because they are primarily released as heat, while no more than the 30% will be converted to mechanical work (W. Larry Kenney et al., 2012; Parsons, 2014).

There is also an increase in thyroxin production. Hypothalamic thyrotropin-releasing hormone (TRH) rises, stimulating the thyroid stimulating hormone (TSH) release and ultimately elevating thyroxin production to increase general metabolic rate (Marino, 2002).

Vasoconstriction of cutaneous blood vessels

Activation of the sympathetic vasoconstrictor fibers serving the blood vessels of the skin causes them to be strongly constricted. As a result, blood is restricted to deeper body areas and largely bypasses the skin. Because the skin is separated from deeper organs by a layer of insulating fatty tissue, heat loss is dramatically reduced and shell temperature drops toward that of the external environment (Gonzalez-Alonso, 2012; Kenny et al., 2010; Tansey et al., 2015).

Shivering

Muscles receive the efferent feedback from the posterior nucleus of the hypothalamus to cause shivering. This is an effective way to create and maintain heat because the rate of production is high and the human stay still, reducing the heat lost to the environment through convection (Tansey et al., 2015).

Non-Shivering thermogenesis

The sympathetic nervous system releases epinephrine and nor-epinephrine in response to cold exposure, causing anaerobic glycolysis and a release of free fatty acids from fat stores (W Larry Kenney et al., 2015; Tansey et al., 2015).

Piloerection

Innervated by the autonomic system, the stimulation of the sympathetic nervous system causes the contraction of the erector pili muscles (a small band of smooth muscle that connects the hair follicle to the connective tissue of the basement membrane in non-glabrous skin). This erection reduces the air convection movement, reducing heat loss (Kenny et al., 2010; Tansey et al., 2015).

BEHAVIOURAL THERMOREGULATION

The human thermoregulatory system relies primarily on behavioral adaptation and secondarily on autonomic and endocrine responses for thermal homeostasis. This is because autonomic and endocrine responses have a limited capacity in preventing hyper/hypothermia in extreme environments. Changes in human behavior can be extremely effective in response to different changes in body temperature (Flouris et al., 2015). Human can consciously and intentionally alter the heat exchange that is taking place in the environment. This behavioral control is influenced by many different areas of the brain medulla oblongata, pons, midbrain, somatosensory cortex, amygdala, thermoregulatory centers in the hypothalamus as well as the pre-frontal cortex (Flouris, 2011; Tansey et al., 2015).

Responses such as seeking shelter from extreme heat, grabbing a sweater, staying in the shade, consuming ice-cold drinks, etc, are just some of the different strategies that consciously affect and might modify the outcome of body's thermoregulation.

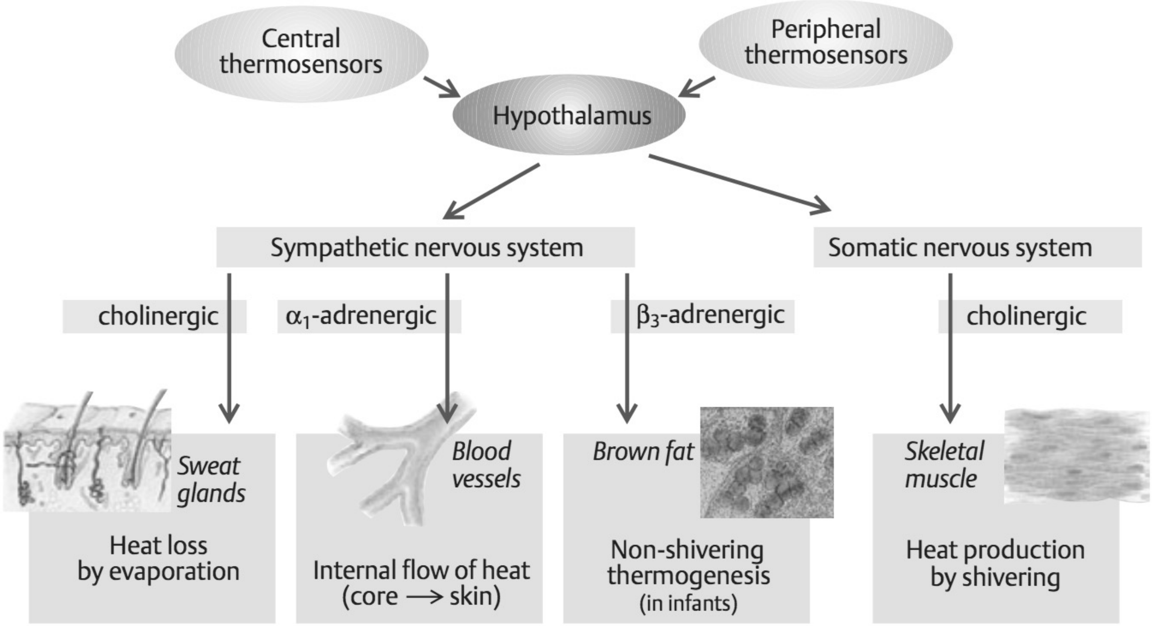


Figure 4. Neural factors affecting thermoregulation, extracted from Silbernagl et al. (2015)

Table 2 . Summary of the physiological and behavioral responses to the activation of thermal receptors. Extracted and adapted from Tansey et al. (2015)

Body Temperature Stimulus	Effectors	Responses
Increase	➢ *Skin Blood Vessels*	➢ Arteriolar vasodilation ➢ Arteriovenous vasodilation
	➢ *Sweat Glands*	➢ Sweating
	➢ *Endocrine Tissue*	➢ Decreased metabolic rate
	➢ *Behavior*	➢ Reduced activity ➢ Stretched body position ➢ Loss of appetite
Decrease	➢ *Skin Blood Vessels*	➢ Arteriolar vasoconstriction ➢ Arteriovenous vasoconstriction
	➢ *Arrector Pili Muscles*	➢ Piloerection ➢ Air trapping
	➢ *Skeletal Muscles*	➢ Shivering thermogenesis
	➢ *Endocrine Tissue*	➢ Increased metabolic rate (adrenal and thyroid glands)
	➢ *Behavior*	➢ Increased activity ➢ Huddled body position ➢ Increased appetite
	➢ *Brown Adipose Tissue*	➢ Non-shivering thermogenesis

1.5 Exercise and Thermoregulation

During exercise, the body is facing a superior thermal stress load compared to resting conditions. As in a rested state, there are heat balance mechanisms that take part in the process, however, exercise increases endogenous heat production in both warm and cold conditions. When exercising, the release of energy as heat enhances the activation of the heat loss mechanisms. For this to happen, excess heat has to be transported from the core to the skin to be lost via convection to the environment (Fig. 5).

The inefficiency of metabolic transfer during exercise liberates approximately 30-70% of energy generated by skeletal muscle substrate oxidation as heat (Bangsbo et al., 2001; Gonzalez-Alonso et al., 2000; P. Krustrup et al., 2001). Exercise enhances the activation of the physiological mechanisms in charge of heat loss in order to prevent an exponential rise in body core temperature that might reduce performance and, in case of an excessive increment of internal temperature, prevent the risk of developing a hyperthermia related health illness (Wendt et al., 2007).

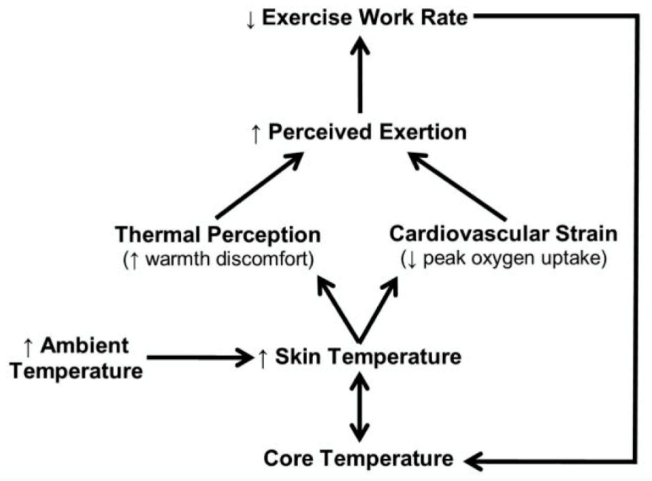


Figure 5. The proposed manner in which thermal perception and/or cardiovascular strain mediate reductions in exercise work rate in the heat through their impact on perceived exertion. The reductions in exercise work rate are modulated predominantly via increased skin temperature and ultimately control the rate of rise in core temperature. Extracted from Flouris et al. (2015)

1.5.1 Thermogenesis and Thermolysis

During physical activity and exercise there is a rise in the rate of heat production (thermogenesis) because of the liberation of energy from the body's metabolic systems (W Larry Kenney et al., 2015). To create this energy, cells generate ATP (Adenosine triphosphate) through three different processes: the ATP-PCr (phosphocreatine) system, the glycolytic system and the oxidative system. These reactions are anaerobic and do not require oxygen to produce energy. Initially, these reactions are delivered by the ATP-PCr system (up to 20 seconds), which total heat production in contracting skeletal muscle is closely matched with changes in heat liberation during ATP production during the very first stages in exercise (Bangsbo et al., 2001; Gonzalez-Alonso et al., 2000; P. Krustrup et al., 2001). Then, anaerobic glycolysis occurs (1-2 minutes). The only limitation lies in the buildup of lactic acid, resulting in an acidification of muscle fibers effectively shutting off glycogen breakdown and interfering with actin-myosin cross-bridging thus halting continued physical activity (Enoka et al., 1992). Although, during oxidative phosphorylation processes energy production for ATP resynthesis is greater compared to anaerobic processes, and it becomes the primary energy system if the exercise lasts more than 1 minute.

As stated by Gonzalez-Alonso et al. (2000), heat production is doubled after 3 minutes of intense physical activity, although half of the amount increased happens during the first 38 seconds. Meanwhile, anaerobic energy source contribution to heat production is greater at the beginning of the exercise, becoming smaller as aerobic energy turnover increases (Bangsbo et al., 2001; P. Krustrup et al., 2001)

In contrast to thermogenesis, heat loss (thermolysis) responds within a short delay (Carter et al., 2002; Gleim et al., 1981) after physical activity has begun. At the beginning of exercising, heat production is released and stored in the active muscle to increase and achieve an optimal working muscle temperature (Houmard et al., 1991; Johnson, 1992; Mohr et al., 2004). Along with the duration of exercise, the increment of blood flow through the muscle capillary with the conductive heat transfer to adjacent organs will redistribute metabolic heat to the core, initiating an increase in vasodilation and skin blood flow (Gonzalez-Alonso et al., 2003; Johnson, 2010).

Heat storage is the result of the equation between thermogenesis and thermolysis, which during exercise has a positive outcome. Although, is important to take in consideration that the rise in core temperature is also given by body mass and body composition amongst others factors such as fitness levels, sex or age.

1.5.2 Heat Exchange during exercise

Heat exchange is a crucial process during high intensity exercise, depending on the interaction of heat production and heat dissipation. Excessive heat stored or liberated might impair human performance due to a deteriorated function of cellular and organ systems (José González-Alonso et al., 2008; N. A. Taylor et al., 2008). According to Gonzalez-Alonso (2012) there are two approaches to heat exchange inside the body: intercellular conductive heat transfer and vascular convective heat transfer.

As stated before, due to the low metabolic rate and constant blood flow, heat is transferred from core to skeletal muscle tissue, giving the muscles a resting constant temperature that oscillates between 33°C and 35°C. When exercise starts, mechanical work increases muscular temperature, leading to a reversal of the temperature gradient between muscle and arterial blood (Tansey et al., 2015; Wendt et al., 2007). Heat is now transferred from muscle to blood and redirected to the body core, increasing core temperature. Subsequently, heated blood is directed peripherally to the skin, this is being determined by the temperature gradient between them and the skin conductance through subcutaneous fat and circulation (Nadel, 1984). When metabolic heat is transferred to the skin, the processes to lose it to the surrounding environment are activated. Radiation, conduction, convection and evaporation are used to balance the heat storage equation.

The hypothalamus receives either the heat sensitive or cold sensitive neuron afferent information, monitoring the temperature of the blood flow and detecting changes peripheral and internal changes in temperature. The subsequent response of the hypothalamus is sent by the anterior or posterior nucleus of the hypothalamus initiating the thermoregulatory balance response for any given thermal stress (Boulant, 1998, 2000). The critical threshold temperature in the hypothalamus to initiate thermal regulation processes is ≈37°, establishing this body temperature as a "set-point" to bring back when there is an imbalance.

1.5.3 Cutaneous vasodilation

When the thermal receptors send a feedback to accelerate the heat loss process, cutaneous vasodilation and sweating are the principal methods. The modulation of skin blood flow (SkBF) is an effective mean to adjust the cutaneous vasomotor tone, hence, the heat flux brought in close proximity to the skin's surface from the core. The cutaneous circulation acts as a major effector of the thermoregulatory response, although it may be affected by non-thermal responses such as the baroreflex.

One of the effects of exercise and the vasomotor reflexes, is the redistribution of blood flow from the inactive tissue to the to where an increased metabolic demand is required by skeletal muscle. The autonomic nervous system plays a major role in control of blood flow the skin (Charkoudian, 2003). "Non-glabrous skin (hair-bearing) is innervated by noradrenergic vasoconstrictor and cholinergic vasodilator nerves whereas glabrous skin (non-hair-bearing), present on the palms, soles and lips is innervated solely by vasoconstrictor nerve fibers" (Charkoudian, 2003; Tansey et al., 2015).

During physical activity, thermoregulatory and non-thermoregulatory responses may happen simultaneously, leading the cutaneous circulation to conflicting demands (Kellogg et al., 1991; Tansey et al., 2015; Wendt et al., 2007). Even when the response of SkBF is vasodilation, there is evidence of cutaneous blood vessels vasoconstriction, even when developing a hyperthermic state during exercise (Kellogg et al., 1993; W. L. Kenney et al., 1992). The sympathetic nervous system controls cutaneous circulation through "a noradrenergic active vasoconstrictor system and an active vasodilator system of uncertain neurotransmitter" (W. L. Kenney et al., 1992; Wendt et al., 2007). SkBF is also a thermoregulatory efferent response that may be altered by non-thermoregulatory responses such as baroreflexes, maintaining blood pressure during hyperthermic conditions.

1.5.4 Sweating

The activation of eccrine sweat glands, causes sweat to be secreted onto the skin surface, hastening heat loss by evaporation of the water content of the sweat. Actually, sweating is the only mechanism of heat loss once ambient temperature exceeds body temperature. These eccrine glands are innervated by sympathetic cholinergic nerve fibers and cover most of the body (Shibasaki et al., 2010; Shibasaki et al., 2006). This stimulation elicits the secretion of a fluid that resembles plasma although without the proteins. Performance also depend on the body water and electrolyte balance, because both act as a facilitator of the biochemical reactions within cells and tissues and it's very important for maintaining blood volume (Mack et al., 2010; Sawka et al., 2000). Electrolytes are fundamental to move fluid between extracellular and intracellular space as well as to produce cell membrane potentials. Physical activity secrets an average of 1L of sweat during moderate intensity exercise (Sawka et al., 2000; Shibasaki et al., 2006). This loss of water also leads to a loss of electrolytes. The main elements present in sweating are sodium chloride, potassium, calcium, and magnesium although these last three in less quantity than sodium chloride (Amano et al., 2011; Journeay et al., 2005; Tam et al., 1978).

Evaporation of sweat allows heat to be transferred to the environment as water vapor from respiratory passages and the skin surface. Even though this is the main heat loss method during exercise, one of the major issues is the availability of water for sweat production, leading to a reduction in plasma volume, hence hastening fatigue by increasing core temperature and blood flow restrictions. Heat acclimatization enhances the sweating mechanism and is also associated with a redistribution of sweat secretion towards the limbs (Hofler, 1968; Shido et al., 1999).

1.6 Thermoregulation of Exercise in the Heat

Exercise in the heat is a challenging state for the body to keep the demands of exercise intensity at optimal conditions. Blood flood to active muscles is essential to make the muscles work, and fulfill the oxygen demands during physical activity. At the same time, redirecting blood flow to the skin is essential to meet the demands of body's thermoregulation. Hence, there seems to be a complex process for the cardiac output to supply all the demands during hyperthermia induced by the high temperatures of the environment and exercise. It seems that failing the supply of blood flow to the muscle will limit exercise performance while reducing the skin blood flow won't help to accomplish thermal balance with a subsequent elevation of core temperature.

During exercise the gradient temperature between muscle and surrounding skin narrows, but heat conductance through the human tissues in the human body is barely affected. In this thermal stress case, a major role is played by convective heat transfer from active muscles to the core of the body, depending on tissue blood flow and arteriovenous blood temperature difference (Gonzalez-Alonso et al., 2000). Furthermore, to meet thermoregulatory purposes, skin blood flow must increase. Therefore, a redistribution of cardiac output may be directed to the skin, thus an increased heart rate becomes necessary (Nybo, 2008; Rowell et al., 1965). When the capacity of the body to maintain cardiac output struggles due to; a long duration exercise, an increment of physical activity intensity or another heat related issue, and the body isn't able to dissipate the endogenous heat production, core temperature increases and stroke volume declines (Gonzalez-Alonso et al., 1995; Nybo, 2008). This lower stroke volume seems to be "a combined effect of reductions in cardiac filling pressure due to reduced central blood volume and a shorter diastolic filling time that will reduce both right and left ventricular end-diastolic volumes and subsequently cause a lowering of the stroke volume" (Fritzsche et al., 1999; Nybo, 2008).

The control for skin circulation includes different thermoregulatory and non-thermoregulatory reflexes controlling blood pressure control such as central command, muscle metaboreceptor and mechanoreceptor stimulations (Shibasaki et al., 2005). Neural control modifies the response depending on the feedback received by these receptors, giving an efferent response conducted by noradrergenic vasoconstrictor nerves and a sympathetic active vasodilator involving cholinergic cotransmitters, in both glabrous (non-hairy) and non-glabrous (hairy) skin, although non-glabrous is always related exclusively to this activation of the vasodilation system response (Johnson et al., 2010; Kellogg et al., 2007; Kellogg et al., 1995).

Another major issue during exercise in the heat, is the loss of water during exercise under hot conditions. This environmental stress has as a result a higher sweat rate that leads into a dehydration. In such conditions, cardiac output reduces its stroke volume declining muscle blood flow (Cheuvront et al., 2010; Gonzalez-Alonso et al., 1998; Wendt et al., 2007) and a reduction of blood plasma (hypovolemia) that might restrict blood flow into the tissues (Azad et al., 2016; Maughan et al., 2004).

During moderate hyperthermia, "muscle VO2 is preserved because the arteriovenous oxygen difference widens as combined effects of hemoconcentration that increases the arterial oxygen content and a slightly higher oxygen extraction, which lowers the venous oxygen content" (Gonzalez-Alonso et al., 1998; Nybo, 2008). Despite maintaining VO2, the detrimental situation of dehydration and a reduction in muscle blood flow increases the production of leg lactate and hastens the glycogen phosphorylation (Gonzalez-Alonso, Calbet, et al., 1999), which reduces performance during submaximal and maximal exercise, and it seems to be accelerated under severe hyperthemic hot and humid conditions with a simultaneous increment in core temperature and skin temperature reducing also VO2 max. (Arngrimsson et al., 2003; Nybo, Jensen, et al., 2001).

During severe hyperthermia and under a dehydration state, the increment of arterial content and its hemoglobin concentration doesn't counterbalance the previously mentioned reduction of blood flow which will decline muscle's VO2.

An enhancement of the anaerobic metabolism leading to a faster reduction in muscle ATP and Creatine Phosphate (ATP-PCr) levels, which is rapidly going to increase muscular lactate rate and H+ accumulation (Gonzalez-Alonso et al., 2003), impairing contractile properties of skeletal muscles. Along with dehydration, the progressive reductions in cardiac output and arterial pressure also have as a result elevations in systemic vascular resistance, cutaneous vascular resistance and plasma noradrenaline levels (Gonzalez-Alonso et al., 1998; J. González-Alonso et al., 2008; Gonzalez-Alonso et al., 1995). This will contribute to peripheral fatigue and the capacity to create peak power or average power output during series of repeated efforts, such as sprints or consecutive jumps, due to a declination of pH and an alteration of the accumulation of substances involved such as plasma K+, H+, and Ca2+ and muscle lactate (Drust et al., 2005; Fitts, 1994; Lamb et al., 2006); glycogen use (Maxwell et al., 1999; Morris et al., 2005) or plasma ammonia, glucose, or free fatty acid concentration.

Another hyperthermia induced effect is hyperventilation, lowering arterial carbon dioxide tension and consequently also reduces the cerebral blood flow by as much as 20–25% (Nybo et al., 2014). Although some studies seem to agree that maximal exercise under heat stress conditions does not seem to impair brain aerobic metabolism, even though brain blood flow and oxygen delivery decline (Bain et al., 2015; González-Alonso et al., 2004; Meeusen et al., 2006). Furthermore, González-Alonso et al. (2004) implies that brain aerobic metabolism is enhanced because "the increase in O2 extraction outstrips the decline in blood flow".

We can relate the impairments of aerobic capacity and high intensity exercise performance during hyperthermic conditions to the impossibility of the cardiac muscle to maintain its output, failing in the delivery and supply of oxygen to active muscle implicated in physical activity, because of its direct temperature influence on the central nervous system.

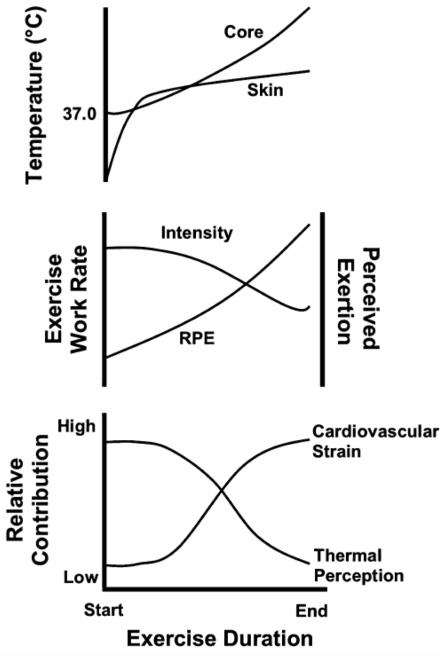


Figure 6. Proposed relationship between cardiovascular strain and thermal perception as mechanisms dictating thermoregulatory behavior under hot conditions. Extracted from Flouris et al. (2015)

1.7 Thermoregulation of Exercise in The Cold

Cold exposure during physical activity has a modification of homeostatic responses at rest and during exercise. The most important alterations are an increased thermogenesis and peripheral vasoconstriction.

Exercise in cold environments stimulates sympathoadrenal activity, eliciting secretion of catecholamine and cortisol, making changes in immune function (Kim et al., 2014; Wilkerson et al., 1974). This alteration in the immune system during exercise in cold environments is a result from modifications in blood flow redistribution, plasma volume and cardiac output (Telford, 1998). Some of the adaptations to cold exposure are the low thermogenic threshold, improved cold tolerance and greater thermoregulatory sensitivity (Kim et al., 2014). Although it can also interfere in training adaptations, reducing sympathetic responses and rates of glycogenolisis and lipolysis, as well as promoting vasoconstriction (Jett et al., 2006).

The principal function of skin blood flow, besides fulfilling the requirements of cutaneous tissues, is the control of heat exchange from the body core to the periphery. During cold in exercise environments, heat conservation is one of the main objectives of blood flow. A cutaneous veno and vasoconstriction due to the low environmental temperatures reduces skin temperature and the gradient between skin and the surrounding medium. This modification in vascular tone is elicited via adrergenic receptor activation and its effect on blood vessel diameter as well as an elevation in plasma norepinephrine concentration, resulting in a rise in mean arterial pressure, cardiac output and stroke volume (Stocks et al., 2004; N. A. Taylor et al., 2008).

Some of the physiological responses during submaximal exercises in the cold include a lower heart rate compared to normothermic conditions, probably because the parasympathetic activation of the baroreflex receptor, and "a blunted epinephrine response which serves to prevent an increase in core temperature during exercise in cold conditions" (Kim et al., 2014; Parkin et al., 1999). Vasoconstriction limits the heat loss via convection and evaporation as well as redistributes blood to the core, causing increased stroke volumes and a reduced heart rate (Fritzsche et al., 1999; Gonzalez-Alonso et al., 2003; Wilcock et al., 2006). Also, Kim et al. (2014) found a higher blood lactate concentration compared to cold acclimatized athletes, after submaximal exercise, which might be a result of a lower aerobic metabolism and reduced clearance of lactate, involving activation of the sympatho-adrenal system and greater lipid metabolism during exercise (Stainsby et al., 1990; Tipton et al., 1997). Another cold effect is the increment of norepinephrine concentrations, hence sympathetic nervous system, mediating and modulating the immune function (Castellani et al., 2001; Castellani et al., 1999; Telford, 1998).

1.8 Cooling

Based on the assumption that exercise causes an increment in core temperature which at some point is going to start reducing the ability of the athlete of perform high intensity activities, abilities such as repeated sprints or jumps, or the capacity to take decisions seems to be reduced when internal temperature rises. While this rise during normothermic activity seems to increase at a regular rate so the body is able to cool itself by radiation and convection through sweating, when this physical activity occurs in hot conditions during a long time it may put the athlete's health and performance at risk by an increased body thermal load (C. C. W. G. Bongers et al., 2017; Stevens et al., 2016).

An elevated core temperature can lead to the development of severe heat illnesses, such as a heat stroke (Barr et al., 2009; Clapp et al., 2001; Cotter et al., 2001). As an attempt to reduce the detrimental effects of uncompensated incremented core temperatures induced by high intensity physical activity and heat stress, some precooling methods have been used to reduce skin and core body temperature before practice and competition. Even the organization of some major sporting events taking place in hot and humid climatic conditions, such as the Summer Olympics Games (e.g., Rio de Janeiro 2016), FIFA World Cup (Brazil 2014 or Qatar 2022) or the Tour de France, recommend strategies to attenuate the effects of thermal load (S Racinais et al., 2015).

Furthermore, reducing the core temperature as a safety method is not the only objective to apply a cooling method before exercise in the heat. The ability to reduce internal thermal load before the competition to improve performance, and enhancing recovery between halves of a game or bouts of practice has also been in the spotlight. Finally, one of the most common uses of cooling is done as a post exercise recovery enhancer. Reducing the recovery time to get the athlete ready for the next exercise session has been in the spotlight for so long and whole body or partial cryotherapy and cold water immersion have been the most popular systems used due to its proven reduction of core and skin temperature, inflammation, heart rate, cardiac output and fatigued perception in fatigued and hyperthermic athletes (Marino, 2002, 2008).

1.8.1 Cooling Methods to Enhance Performance

Different cooling methods have been used to attenuate the effects of hyperthermia induced either by the environment, the exercise or both to enhance performance during exercise. The different modalities normally used can be divided by the different parts of the body that are affected by the exchange of temperature. We divide these methods in three groups: Whole Body Cooling (WBCool), Local Cooling (LC) and Internal Cooling (ICool)

Whole body cooling implies a large part of the body affected or covered by a cooling agent. The skin as a large organ is the principal organ affected by these methods, enhancing the exchange of heat and cooling through this method (Booth et al., 2001; Kay et al., 1999). Local cooling has only a part of the body in contact with the cooling method. It can be used as an anti-inflammatory method as well as a recovery enhancing method if applied in areas that have a direct implication with thermosensor, increasing the feedback received by the thermoreceptor and thermosensitive afferent hastening the physiological response of the body (Arngrimsson et al., 2004; C. Hayashi et al., 1996; Stannard et al., 2011). The third method, internal cooling is based on the ingestion of water and ice combinations to replace fluid loss and cool internal thermoreceptors in the esophagus and stomach, that are close to the core of the body (James et al., 2015; Mitchell et al., 2001).

The decision of using WBCool or LC is based on the individual needs of the athlete, the sport, the timing, accessibility, space required to use the cooling modality, and the equipment or clothing requirement of the sport (Adams et al., 2016). It's important to note that during sports the athlete must feel comfortable in order to maximize performance, so the cooling method shouldn't be a problem. On the other hand, budget is also an important factor, although cooling can be applied with a large variety of nonexpensive modalities as well as practical methods to help the athlete during the recovery time.

The timing of application is also important to as the procedures of application might be different: Precooling (before the exercise), percooling (during the exercise), midcooling (between halves of a game or bouts during practice) and postcooling (after the exercise).

1.8.2 Whole Body Cooling

COLD AIR EXPOSURE

Cold air exposure (Azad et al., 2016; van Ooijen et al., 2004) is a cooling method demonstrated to reduce skin and core temperatures (Azad et al., 2016; J. K. Lee et al., 2014) in which the objective is to enhance a series of natural physiological responses to defend deep body temperature, such as a vasoconstriction and a reduction in conductive heat transfer from the core to the skin, resulting in a redirection of warm blood from the periphery to the central system (Ross et al., 2013).

COLD WATER EXPOSURE

In some sports practices in the heat, cold water exposure has been an effective method to cool down core and skin temperatures (Peiffer et al., 2010; Vaile et al., 2011; Yeargin, Casa, McClung, et al., 2006). One of the important facts is that this cooling method is easy to use and doesn’t need any kind of special facility or equipment. Traditionally, showers or water sprays have been used as cold water exposure methods to attenuate the heat stress thermal effects.

WATER IMMERSION

Water immersion is another common method use to decrease skin and core temperature (Luhring et al., 2016; Pointon et al., 2012; Roberts et al., 2014). This method has been used in different ways, different constant water temperatures and also gradually decreasing water temperature. The skin as a large organ with a substantial mass, benefits from this method because of the large amount of the body that is in contact with water, which might induce a greater heat storage capacity and a reduction in sweat production (Demartini et al., 2015; Mawhinney et al., 2017).

WHOLE BODY CRYOTHERAPY

Whole body cryotherapy (WBC) is another common method used as a cooling method. Although is often used a post exercise recovery method, there has been some studies using it to diminish the heat stress effects before exercise (Bleakley et al., 2014; Costello et al., 2012). Exposure to WBC is usually between 2 and 3 minutes, with a preparation time of 30 seconds in a cryochamber at a temperature of -60ºC (Al-Nawaiseh et al., 2016; Banfi et al., 2010; Bouzigon et al., 2016). This treatment is applied to relieve pain and inflammatory symptoms, decrease pro-oxidants having high potential benefits on sports-induced hemolysis and cell and tissue damage (Algafly et al., 2007; Banfi et al., 2010; White et al., 2013).

1.8.3 Local Cooling

COOL VEST / ICE VEST

Cool or Ice vests have been reported to significantly decrease skin temperature, which might lead to a skin vasoconstriction, decreasing skin blood flow and the exchange between the body and the cooling garment (Arngrimsson et al., 2004; Cotter et al., 2001; DeMartini et al., 2011; Hunter et al., 2006), although it also enabled the exchange of heat between the cooling vest and the skin, due to its powerful heat transfer capacity absorbing the ice and melting into water. The contact a cool vest jacket has with the upper body, thermosensitive and spine receptors make the cool vest an efficient method to cool down skin temperature (DeMartini et al., 2011; Lopez et al., 2008).

ICED TOWELS

Iced towels might be a good and low cost alternative to cool the body. Some studies have proven its benefits in performance before starting the exercise (Casa et al., 2012; Minett et al., 2011). The ice towels should be refreshed after 2 or 3 minutes to maintain the cooling effect.

ICED BAGS

Iced bag placement on peripheral arteries such as the axillae, groin, back of the neck, allows the blood passing through the arteries, seems to help reduce body temperature cooling the blood in the arteries then circulating through all the body (Kielblock et al., 1986; Wegmann et al., 2012).

1.8.3.1 Local Cooling Placements

HAND COOLING

Hand cooling evidence states that cooling hands results in an attenuated rise of body temperature due to its condition of glabrous skin innervated by vasoconstrictor nerve fibers (Charkoudian, 2003; Tansey et al., 2015) . Results are contradictory, showing that palm cooling has no effect on heat strain or performance (Amorim et al., 2010; Scheadler et al., 2013) or it has a performance benefit delaying fatigue during high intensity and endurance exercise (Kwon et al., 2010; Kwon et al., 2015).

NECK COOLING

Neck cooling has an special consideration due to its proximity to the thermoregulatory center and a region of high alliesthesical thermosensitivity (Cotter et al., 2005), as well as a practical location in the body to apply the neck cooling collar. It has been found to have a better cooling effect than cooling the same surface area in the trunk although it doesn’t seem to have any measurable effect on peripheral biochemical response so endurance exercise (J. K. Lee et al., 2014; Tyler et al., 2011). Some studies have shown to improve repeated sprint performance in the heat (Sunderland et al., 2015; Tyler et al., 2010) and some benefits in cognitive function and thermal sensation in a hot environment (Ando et al., 2015; J. K. Lee et al., 2014).

HEAD COOLING

Wearing a cooling device on the head such as helmets that might store cold water inside or helmets that pump cold water to cool different parts of the head. Heat exchange between the athlete and the device is done via conduction to reduce core body temperature. The results are not conclusive although some studies have found a cool device to attenuate body temperature during exercise (C. Hayashi et al., 1996; Mundel et al., 2007) meanwhile others found no difference compared to a control group (Ansley et al., 2008).

FACE COOLING

Face cooling is also another place used for local cooling method as It has been suggested that cool facial blood returning to the brain is a means by which brain temperature may be lowered (Al Haddad et al., 2010; Mundel et al., 2007; Mundel et al., 2006) improving thermal comfort (Mundel et al., 2006).

1.8.4 Internal Cooling

HYDRATION

Hydration is the most used method to lower body temperature during exercise (Bandelow et al., 2010; Davis et al., 2016; Ihsan et al., 2016). Replacing lost fluids to keep hydration at an optimal status is important to maintain the thermoregulatory processes functioning and the sweat rate. Its benefits to performance by maintaining core temperature and blood flow during endurance exercise have been proven by some authors (Bandelow et al., 2010; Maxwell et al., 1999; S Racinais et al., 2015; Shirreffs et al., 2000).

ICE SLURRY INGESTION

Based on enthalpy of fusion, ice has a greater heat absorption rate to change from solid to liquid, providing a greater cooling effect than water of a similar temperature (Jones et al., 2012; Siegel et al., 2012; Stevens et al., 2016; Wimer et al., 1997). Besides the possibility of an improvement in exercise performance in the heat, it may also have an effect on internal thermoreceptors located near the core itself, stomach and small intestine (Ali et al., 2007; Dugas, 2011; Hasegawa et al., 2006; Siegel et al., 2010).

1.9 Precooling

One of the most extended strategies to improve physical performance in normothermic and hot environmental conditions is cooling before the activity (precooling). When an athlete is cooled before physical activity, the performance decrement can be counteracted (Bogerd et al., 2010; Duffield, 2008), increasing the time taken to reach a critical thermal peak, preventing an excessive heat storage during exercise in the heat, attenuating thermoregulatory and cardiovascular strain and dehydration, especially at the onset of physical activity (Arngrimsson et al., 2004; Brade et al., 2014).

Some studies stated that the success of this method depends on 2 issues: The first being the skin surface area covered and the intensity of cooling (C. C. Bongers et al., 2015; Price et al., 2002), which might be of interest to efficiently cool the body and reduce skin and core temperature, and secondly the duration of the cooling method (Brade et al., 2010; Lopez et al., 2008). Unfortunately, not all of them are considered easy to use or practical during a competition or practice.

The reduction in stored heat is likely to be a contributor to a "delayed onset of neurally-mediated peripheral vasodilation and sweating mechanisms" (Duffield et al., 2007; Kruk et al., 1990). Also, it has been stated that cold air exposure reduced sweat rate and attenuated plasma volume decrement during exhaustive test under heat conditions (Azad et al., 2016; Duffield et al., 2003), improving the rate of dehydration. A lower or unchanged heart rate has been found after precooling but a posterior improvement in performance was also found (Kay et al., 1999; Olschewski et al., 1988; Quod et al., 2006). A lower heart rate increases stroke volume due to a higher myocardial contractility, eased by a reduced internal temperature and sympathetic activation (Arngrimsson et al., 2004; Gonzalez-Alonso, Calbet, et al., 1999; Wegmann et al., 2012).

One of the largest precooling effects is found in endurance exercise. Precooling seems to change the sensory feedback of the thermoregulatory afferent feedback, attenuating the protection mechanism of the central nervous system

(Castle et al., 2006; Duffield et al., 2007; Wegmann et al., 2012), having benefits on endurance (Quod et al., 2008; Siegel et al., 2010) and improving performance in hot humid conditions (Booth et al., 1997; D. T. Lee et al., 1995; Quod et al., 2008; Ross et al., 2013; Uckert et al., 2007).

Results aren't that clear during high intensity exercise (Ross et al., 2013; Sunderland et al., 2015; Webster et al., 2005). Different studies hypothesize that a redistribution of blood flow from the periphery to the active muscles due to vasoconstriction is the main precursor of precooling before high intensity activity (Sunderland et al., 2015; Wegmann et al., 2012). Nevertheless, It doesn't seem to be an improvement in peak or mean power, distance covered, speed in sessions of maximal sprints of 5-30 seconds' duration (Cheung et al., 2004; Drust et al., 2000; Duffield et al., 2003; Duffield et al., 2007) and no difference in mean or total work done for any kind of cooling procedure (cool bath or ice vest) (C. C. W. G. Bongers et al., 2017; Duffield et al., 2007) stating limited effects on high intensity exercises. Although there has been some performance benefits found after using cold water immersion and neck cooling (Brade et al., 2014; Sunderland et al., 2015), improving repeated sprint ability. Also, we found one study showing detrimental effects on power output and heart rate (Schniepp et al., 2002).

Internal precooling is also a well used method to prevent hyperthermia. Cold fluid ingestion such as water (Hasegawa et al., 2006; Wimer et al., 1997), and ice slurry ingestion (Dugas, 2011; James et al., 2015; Siegel et al., 2010) are methods that enhance evaporative sweat loss and attenuated thermoregulatory, cardiovascular and subjective strain at the end of exercise (Hasegawa et al., 2006) as well as to complete fluid replacement to equal fluid loss.

1.10 Percooling

Percooling is the application of a cooling method during the exercise to attenuate the increment of Tc and improve physical activity performance. It seems that percooling might be more useful than precooling to maximize performance because core temperature is higher during exercise and competition compared to resting conditions or after warm-up conditions, especially during endurance exercise (Kenefick et al., 2007; Tyler et al., 2015). With a higher level of heat stress cooling during exercise might have a greater potential to prevent a significant rise in thermal strain, slowing down the rate in which core temperature is increasing thus maintaining performance (Marino, 2002; Tyler et al., 2015).

Although the largest cooling surface might contribute better to the attenuation and reduction of internal temperature, the most important complication about cooling during exercise is that the application of cold mustn't impede athlete's actions, abilities or skills performance because of an excess of weight and/or skin irritation during the use of a cooling method during exercise. The methods that fit better and have been used during physical activity have been cooling vests, cold water ingestion, cooling packs and mixed cooling methods. According to the aforementioned assumption, cooling or ice vests should be the most effective methods due to their impact on a larger body surfaced compared with the other methods.

Some of the studies on percooling, always endurance activities around 60% and 70% of VO2 max, used a neck collar. The results showed no difference in Ts after the application of cooling on the neck, but an improvement in performance, time trial and time of exercise until exhaustion (Tyler et al., 2011; Tyler et al., 2010). The use of face coolers is supported by the high alliesthesial thermosensitivity of head and face, which might present a greater thermoregulatory advantage compared with cooling other parts of the body (Cotter et al., 2005; Shvartz, 1976).

The use of a cool vest also benefitted heat tolerance during exercise (Kenny et al., 2011), improved cycling performance in warm conditions (Luomala et al., 2012). It's been largely proven in firefighters, stating a larger resistance to high temperatures compared with control conditions (Barr et al., 2009; Barr et al., 2011; McEntire et al., 2013).

The effectiveness of cooling during exercise seems to be related to the thermal strain experienced. When the suffered hyperthermia is severe, cooling during exercise might contribute to a better perceptual sensation and perceived exertion (C. Hayashi et al., 1996; Nunneley et al., 1971), having better psychological outcomes that might lead to beneficial changes that might allow to maximize improvements in exercise performance and core temperature attenuation (Tyler et al., 2015).

1.11 Midcooling

Some sports practitioners include some recovery methods between two halves of a game or two bouts of practice in order to enhance recovery to start the following set of exercises in as better physical shape as possible. Active recovery including low intensity endurance activity and rewarm up are the most common methods used (Al-Nawaiseh et al., 2016; Andersson et al., 2008; Barnett, 2006). Although precooling is the most extended cooling method in the literature, midcooling (cooling during two bouts of exercise or halves of a team sport) is a method that effectively can attenuate the effects of fatigue and enhance recovery to face the following bout of exercise in good conditions (Duffield, 2008; Jeffreys, 2005; Leeder et al., 2012; Nedelec et al., 2012).

The practical application of midcooling has to go in accordance with the time of recovery that usually is not too long. In soccer, half breaks lasts 15 minutes, and the players have to go to their benches or changing rooms, and get ready to start the second half, which means the allotted time is actually less than 15 minutes. During this time, the players usually change equipment, clothes, attend coaches' explanations and have some medical or therapeutic assistance, which means that cooling recovery method used has to be flexible, lightweight, and allow the athlete to move around the space (Adams et al., 2016). Cool vests (Duffield et al., 2003; Price et al., 2009), towels and ice packs (DeMartini et al., 2011; Mustalampi et al., 2012) and water or ice ingestion (Stanley et al., 2010) are the most common methods used. Even though cold water immersion or whole body cryotherapy has a higher rate of body cooling, the possibility to reduce muscle's working temperature below its regular contractibility range might reduce athletes' performance and increase the injury risk (Chan et al., 2017; Csapo et al., 2017; Macedo Cde et al., 2016).

Most of the studies found ergogenic benefits attenuating the increment in skin temperature and improving exercise performance (Constable et al., 1994; DeMartini et al., 2011; Mitchell et al., 2001) reducing physiological and perceptual strains. Despite these positive results, not all the researchers found the same outcome. Duffield et al. (2003) didn't find any improvement by cooling between bouts, and Price et al. (2009) only found benefits combining precooling and midevent cooling, but not only applying midcooling.

The underlying mechanism to this responses hinges on the enlarged gradient temperature between the body core and the skin. This great range of thermal gradient eases heat loss by promoting internal heat conduction via blood from the body's core to skin, thus cooling the peripheral blood before returning to the core of the body to cool the core temperature (Chan et al., 2017; Yeargin, Casa, McClung, et al., 2006).

Chapter 2

Thesis Aim

OBJECTIVES

The general aim of this thesis is to see if the application of a cool vest jacket during a passive rest period of 15 minutes (the same as a soccer match), after a fatigue inducer protocol in a treadmill based on soccer intensities and distances in normothermia, and another fatigue induced protocol of repeated shuttle sprint ability under hot conditions has any effect on the neuromuscular function and the physiological recovery profile of a soccer player.

The specific objectives have as an object of evaluation the specific soccer skills and physiological responses assessed in each one of the studies. Every study was performed under a test, re-test basis after the use of the cool vest jacket, to directly evaluate the influence of the cool vest jacket in all of these actions and muscle responses.

GENERAL OBJECTIVE

- ✓ **Analyze the effectivity of a cool vest jacket after the fatigue protocol in normothermic conditions as a recovery method.**

SPECIFIC OBJECTIVES

- ➢ *Assess the effectivity of the cool vest jacket as a modifier of the body temperature in normothermia (Study 1).*

- ➢ *Determine the effects of the cool vest jacket on performance recovery used during the recovery period on a countermovement jump, a drop vertical jump, a sprint and a shoot test (Study 2 and 4).*

- *Evaluate the effects of the cool vest jacket on the contractile response properties of the Biceps Femoris after the fatigued protocol (Study 3).*

- *Differentiate the effects of the cool vest jacket on the kinematics of a drop vertical jump and its effects on valgus and varus alignment during the eccentric phase (Study 4).*

GENERAL OBJECTIVE

- ✓ **Analyze the effectivity of a cool vest jacket after the repeated sprint ability protocol as a recovery method under hot conditions.**

SPECIFIC OBJECTIVES

- *Assess the reduction rate effectivity of the skin temperature wearing the cool vest jacket compared to control conditions (Study 5).*

- *Analyze the effects of wearing the cool vest jacket on heart rate recovery and blood lactate concentration (Study 5).*

Chapter 3

Effects of Halftime Recovery with a Cool Vest Jacket on Core and Skin Body Temperature in a Simulated Soccer Match

3.1 Introduction

The effect of thermal factors on the human body has been a therapeutic method applied in medicine and sport practice over many years. Cryotherapy is a frequently used procedure characterized by applying low temperatures in order to treat acute musculoskeletal injuries, relieve pain symptoms, decrease tissue temperature and inflammatory conditions and diminish muscle soreness and inflammation of joints (Banfi et al., 2010; Bleakley et al., 2014; Ma et al., 2013; Marino, 2002).

Some of the most common methods used are whole-body cryotherapy (Bleakley et al., 2014), cold-water immersion baths (Yeargin, Casa, McClung, et al., 2006), cool vest jackets (Duffield et al., 2007), cold towels (Duffield et al., 2007) and ice slurry ingestion (Siegel et al., 2012).

Effects in sports performance have already been studied, stating the theory that lowering core body temperature may enhance heat storage capacity, increasing performance (Booth et al., 1997). Some findings suggest that thermoregulatory strain is decreased due to a redistribution of blood flow towards active skeletal muscles, decreased heart rate, sweat rate and an alteration of skin and core body temperature increasing thermal comfort (Hessemer et al., 1984; Mitchell et al., 2001; Yeargin, Casa, McClung, et al., 2006), representing a common and inexpensive method to improve exercise performance.

Precooling studies have demonstrated the ability to counteract the negative effects of heat stress induced fatigue, enhancing body's capacity to store metabolic and environmental heat, and improving submaximal exercise performance (Cheuvront et al., 2010; Marino, 2002; Quod et al., 2006; Ross et al., 2013), although most of them were performed under ambient temperatures of 30° or higher (Arngrimsson et al., 2004; Castle et al., 2006; Tyler et al., 2015; Yeargin, Casa, McClung, et al., 2006). These findings suggest that cooling is effective at high ambient temperatures, but may also improve thermal comfort while exercising at lower ambient temperatures (Eijsvogels et al., 2014).

Otherwise, cryotherapy as a post exercise therapy seems to decrease inflammation in the musculoskeletal system (Banfi et al., 2010) and reduce the symptoms of DOMS after strenuous exercise (Leeder et al., 2012). The mechanism is basically related to its vasoconstrictive effect, reducing the inflammation reactions through a decrease of the cell metabolism (White et al., 2013). Cryotherapy is used during recovery reports ergogenic benefits, treating muscle syndromes of overuse and reducing the recovery time between training sessions resulting from the attenuation of thermal load (Banfi et al., 2010; Castle et al., 2006; Duffield et al., 2007).

For these reasons pre and post exercise cooling interventions may be considered as a method to enhance performance, improving thermoregulatory and cardiovascular states, throughout physiological benefits in athletic events during breaks such as half times or bouts of exercise (Ranalli et al., 2010). It still has to be established if a cooling intervention induces physiological benefits in team sports, especially those that have only one break or halftime, such as soccer. However, sports events are not always conducted under high ambient temperatures, questioning the effect of cooling under low exogenous heat stress conditions (Galloway et al., 1997; Kenny et al., 1997).

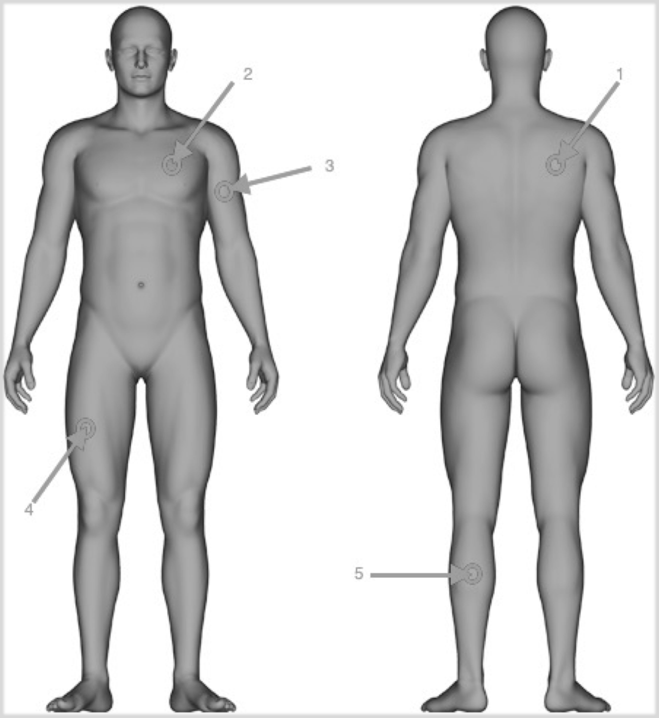
On this basis, we hypothesized that a cool vest jacket applied during the half time (15 minutes) of a soccer match could have physiological benefits enhancing recovery and attenuating the fatigue induced thermal strain in a temperate ambient. Therefore, the aim of this study was to determine the effect of a cool vest jacket during the 15-minute break after a simulated soccer match on a treadmill in Core and Skin temperatures.

3.2 Methodology

Forty physically active males (age 21.9±1.7 years, height 177.4±5.4 cm, mass 73.3±5.6 Kg, body mass index 23.28±1.9, peak oxygen consumption (VO2peak) 57.4±3.1 mL/Kg/min) participated. This study was designed according to the standards of Bioethics committee of the University of Barcelona and according to the principles of the Declaration of Helsinki of 1975, reviewed in 2008. All the experimental procedures were previously explained and the informed consent was obtained from all the subjects.

For a period of 48 h before each trial, the participants were instructed to refrain from strenuous exercise. Furthermore, the participants were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before the test. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials *ad libitum*. The subjects received no economic reward for their participation in the study and had no previous injury in the 6 months prior to the study.

Each testing session was performed in a laboratory chamber at a temperature of 22±1.9°C and with a relative humidity of 30.8±4.8%. Each participant's height, body mass, Skin temperature (Ts) (Infrarred Thermometer, Iberia PCE-891) (right scapula, left chest, left arm in upper location, right anterior thigh and left calf) according to ISO 9886 (9886:2004, 2004)(Fig. x) and Tympanic temperature (Tt) (Ri-Thermo® N.) baseline were measured prior to test recording. Afterwards the participants took part in a 45-minute intermittent running protocol, consisting on five 9-minute running bouts derived from Spanish soccer players match analysis data (Di Salvo et al., 2007) on a motorized treadmill reflecting the time spent in each of the respective speed levels. Speeds were 6.5, 12.5, 16.5 21 and 23 km/h, representing 63%, 14%, 15%, 5% and 3% of the protocol duration, respectively. Intensity levels were organized in a noncyclical manner in an attempt to reflect the nature of a 45-minute soccer game. Unfortunately, the use of a motorized treadmill precluded the inclusion of true sprinting, backwards running and sideways activities. Once finished, the participants were divided in two groups, involving either no cooling or the application of a cool vest during the 15-minute seated recovery (simulating half time). Ts was measured every 5 minutes during the running protocol and the recovery time and Tt at the beginning and at the end of the running protocol and also every 5 minutes during the recovery time. Due to difficulties of registering tympanic temperature during participants' movements, it was impossible to register any throughout the intermittent protocol. Ts was calculated based on Ramathan's equation: 0.3 (Chest + Arm) + 0.2 (Thigh + Calf) (Ramanathan, 1964).



1.- Right Scapula
2.- Left Chest
3.- Left Arm in Upper Location
4.- Right Anterior Thigh
5.- Left Calf

Figure 7. Skin locations to measure temperature.

3.2.1 Cooling Garments

The cooling vest (FlexiFreeze Ice Vest; Maranda Enterprises, LLC. Mequon, WI, USA) uses re-freezable ice sheets to "harness 96 pure water ice cubes into 3 ½ pounds of efficient cooling capability" as marketed by the manufacturer. The vest is light, flexible and is constructed from neoprene being less than 2 cm thick. These vests are charged with 12 re-freezable ice sheets containing 48 ice cubs in the front and 48 in the back attached with Velcro for easy replacement. The ice sheets were stored in the freeze 24 hours before its use.

Figure 8. Cool Vest Jacket, application and ice location.

3.2.2 Temperature Measurements

Tympanic temperature (Tt) was measured by the Riester Ri-Thermo® N thermometer (Jungingen, Germany). The thermometer measured the infrared radiation generated by the eardrum and the surrounding tissue. The technical error of measurements amounted to 0.2 for temperatures in the range of 32.0° to 42.2°.

Figure 9 Tympanic temperature application and thermistor.

Skin temperature (Ts) was measured using the Iberia PCE-891 infrared thermometer (Albacete, Spain), which has a resolution of 0.1° (measuring range -50° to +1600°). The precision of measurement in the temperature range of our test was ±1,5 % of ±2 °C range (manufacturer's information). Measurements were performed in right scapula, left arm in upper location, right anterior thigh and left calf according to ISO 9886 (2004). To ensure measurements were done in the same place, locations were marked with a marker.

Figure 10. Skin Temperature application with the infrared thermometer.

3.3 Statistical Analysis

Descriptive statistics were used to calculate the mean value and standard deviation (SD) for all the variables tested. We calculated a 2-way, wearing cool vest or not during recovery, analysis of variance with repeated measures between the minute 0, 5, 10 and 15 of the recovery on Ts and Tt. We also performed independent *t* tests to identify significant differences between cool vest and control group on the recovery period during the 15 minutes after the protocol ended. Statistical significance was set at $p<0.05$ for all analyses. All data was analyzed using SPSS (Version 23.0.0, Chicago, IL, USA).

3.4 Results

Ts during the intermittent protocol was not significantly different between groups at baseline, 0, 5, 10, 15, 20, 25, 30, 35, 40 and 45 minutes of the intermittent protocol (see table 1), but it was significantly different over time (t=4.560; p<0,0005).

During the simulated halftime period, values in skin temperature between cool vest and control conditions were not significant either at 5 and 10 minutes after recovery started (t=1.276; p=0.209 and t=0.927; p=0.360, respectively) but it was significantly different between groups after 15 minutes of seated recovery time (t=3.965 p<0.005). Also, statistically significant differences were found in the interaction time (from minute 10 to 15 of the recovery period) by group (F=4.167 p=0.048).

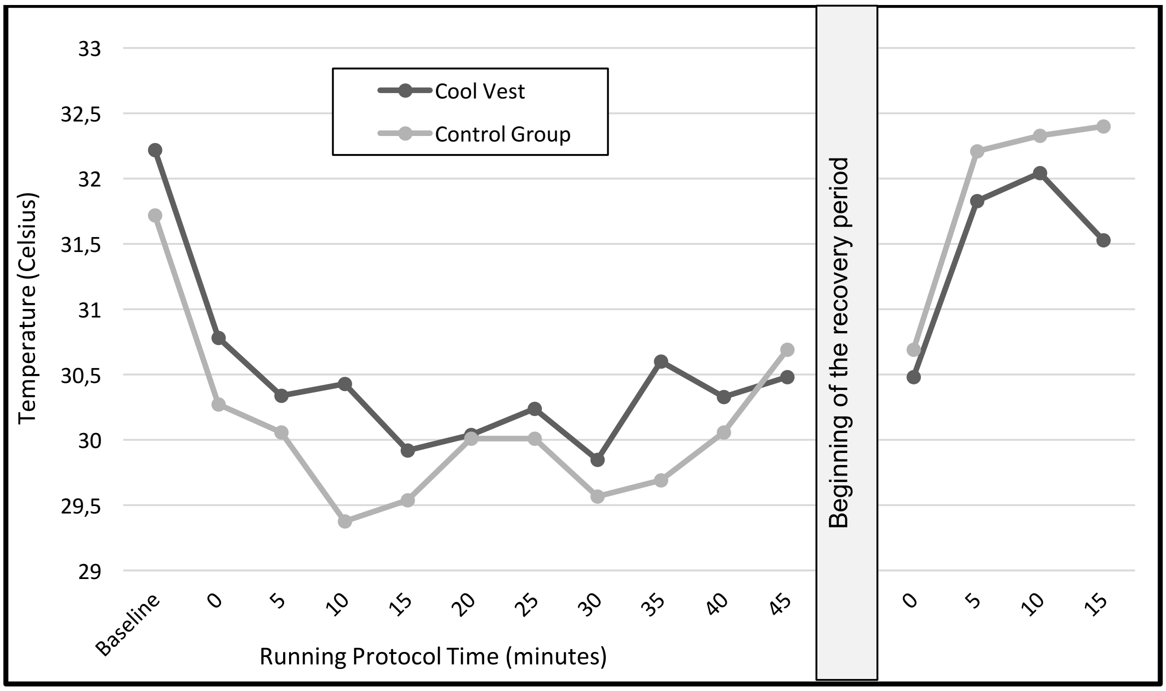


Figure 11. Mean skin temperature during running protocol and recovery with or without cool vest.

Table 3. Skin Temperature (mean Celsius degrees) during the running protocol for Cool Vest group (CVG) and Control group (CG).

	Cool Vest	SD	Control	SD	t	p
Baseline	31.72	1.18	32.22	1.37	0.551	0.707
0 min	30.78	1.17	30.27	0.89	0.354	0.725
5 min	30.34	1.44	30.06	0.80	0.405	0.646
10 min	30.43	1.43	29.38	1.17	1.741	0.127
15 min	29.92	1.60	29.54	1.12	0.822	0.573
20 min	30.04	1.37	29.98	1.22	0.065	0.969
25 min	30.24	1.44	30.01	1.41	0.345	0.735
30 min	29.85	1.61	29.57	1.54	0.375	0.713
35 min	30.60	1.22	29.69	1.60	1.362	0.192
40 min	30.33	1.12	30.06	1.65	0.381	0.708
45 min	30.48	0.91	30.69	1.49	2.058	0.146
Recovery time begin						
5 min	31.83	0.93	32.21	1.01	1.276	0.209
10 min	32.04	0.98	32.33	1.06	0.927	0.36
15 min	31.53	0.87	32.40	0.51	3.965	<0.005*

* Statistically Significant. p<0.05

Baseline Tt was determined during the first visit and right before the intermittent protocol. Tt recovery rates didn’t show any significant differences before or at the end of the running protocol (p=0.992, p=0.304, p=0.368 baseline, after the warm-up and at minute 45) nor during the 15 minutes resting period (p=0.871, p=0.257 and p=0.574 at 5, 10 and 15 minutes after the protocol).

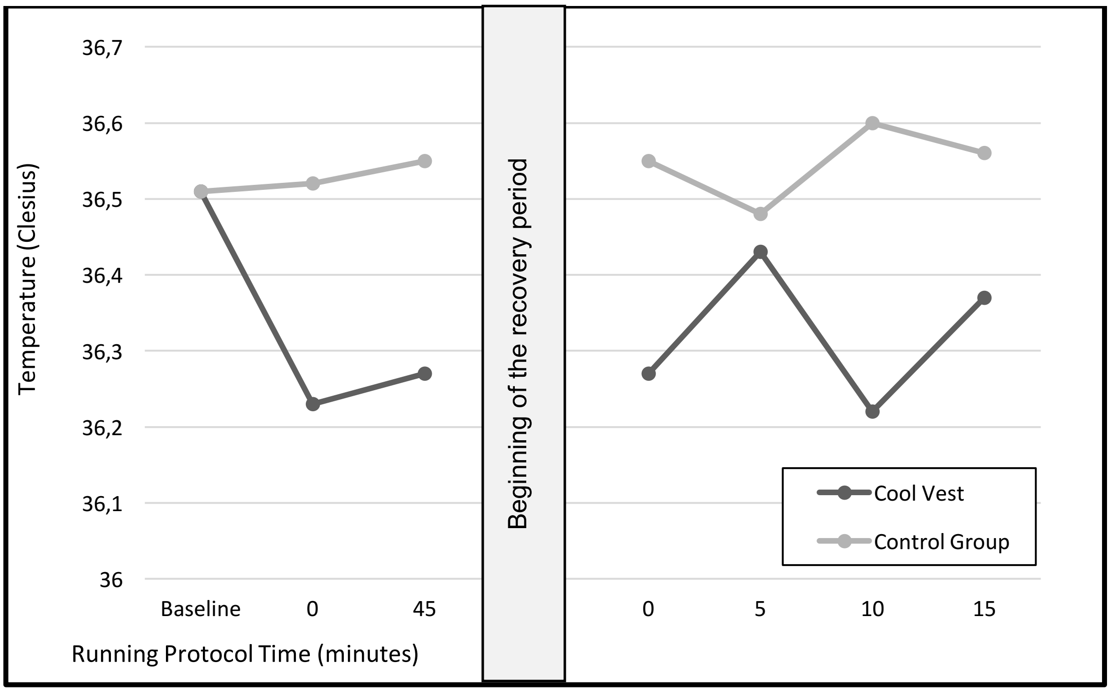


Figure 12. Tympanic temperature of the participants during running protocol and recovery with or without cool vest

Table 4. Tympanic Temperature (mean Celsius degrees and SD) during the running protocol for Cool Vest and Control groups.

	Cool Vest G.	SD	Control G.	SD	t	p
Base	36.51	0.52	36.51	0.43	0.011	0.992
0 min	36.23	0.70	35.52	0.38	1.063	0.304
45 min	36.27	0.74	36.55	0.46	0.926	0.368
Recovery time begin						
5 min	36.43	0.60	36.48	0.77	0.177	0.861
10 min	36.22	0.74	36.60	0.58	1.175	0.257
15 min	36.37	0.76	36.56	0.61	0.575	0.574

*Statistically Significant ($p<0.05$).

3.5 Discussion

The purpose of this study was to evaluate the effectiveness of a cool vest jacket in the ability to lower the Tt, Ts and Tc of individuals, after fatigue induced simulated protocol in a treadmill. The design of this study focused on the 15-minute break that a soccer match has between halves.

This increment will also affect skin temperature which, combined with core temperature, is associated with a decrease performance. To control the oscillation of core temperature without an invasive method, infrared tympanic membrane thermometers are considered ideal because the tympanic membrane and the hypothalamus share and arterial blood supply originating from the carotid artery; therefore, the tympanic membrane is considered to directly reflect core temperature (Chue et al., 2012; Gasim et al., 2013). While body heat storage increases average body temperature, combining core and skin temperature, an increment of skin blood flow response takes part controlled by the vasodilator system and local factors (Ihsan et al., 2016; Priego Quesada et al., 2015). An accurate calculation of skin temperature is done by a weighted average of temperatures across the surface of the skin due to the local variability of responses depending of the type of exercise (Neves et al., 2015), being Ramanathan (1964) one of the most extended and practical formula to use.

Our results show a reduction of the skin temperature after running protocol in the treadmill in lab temperature (22° C), in accordance to other studies that found the same outcome (Chudecka et al., 2010; Merla et al., 2010; Priego Quesada et al., 2015). This temperature reduction has been associated with sweat evaporation for heat dissipation during exercise (Havenith, 2001), which might be limited in environments of high ambient humidity, diminishing the ability to dissipate heat (Cleary et al., 2014; Duffield et al., 2003; Luomala et al., 2012).

Vasoconstriction response and the capability to dissipate the metabolic heat through the skin layers during exercise is an effect caused by an increment in catecholamine release and vasoconstrictor hormones as exercise intensity increases (Johnson, 1992; Priego Quesada et al., 2015; Xu et al., 2013). Although the tendency was to decrease skin temperature, some subjects increased temperature more than others during recovery depending on the predominance of vasoconstriction over vasodilatation or *vice versa* (Merla et al., 2010). This fact indicates the existence of individual response patterns. Therefore, different people exposed to the same temperature have different stress responses. This is mainly attributed to acclimatization, but also aging, gender, type of exercise, intensity, duration, and level of physical fitness have a big effect on this response due, in part, to muscle mass and subcutaneous fat layer (Best et al., 2012; Formenti et al., 2013; Neves et al., 2015) which depends on the physical fitness and affects thermoregulation (Johnson et al., 2010; Johnson et al., 2014) through the evaporation of sweat and circulatory response (Akimov et al., 2010). These differences in body size, configuration and composition explain the capability of individual response before cold exposure.

During fatigue state induced by exercise, between a 70 and an 80% of mechanical work is released as heat that the body stores and subsequently, will exceed its heat loss capacity and result in a rise of core temperature (Ament et al., 2009; Kenefick et al., 2007). During recovery after prolonged exercise, fitter people are able to maintain a warmer skin temperature due to thinner subcutaneous fat thickness and higher metabolic heat production, (Bittel et al., 1988; Blomstrand et al., 1986; Budd et al., 1991) which might lead to a greater effectiveness of the cool vest jacket on trained people better than less fit people.

One of the important outcomes of this study is the capacity of the cool vest to reduce the cooling rate to baseline levels after strenuous exercise. A greater cutaneous vasodilation occurs when Ts oscillates between 33°C and 35°C (Clapp et al., 2001), it's likely that the cool vest induced a vasoconstriction and a significant reduction in cutaneous blood flow and cooling of the tissues beneath, as the body temperature increases during exercise, the demand of skin blood flow would increase, which would be cooled and would reduce core temperature on return to the core via the venous circulation (Price et al., 2009). Wearing the cool vest jacket during different moments prior to exercise such as warm-up, stretching or during recovery reduces sweat rate, core and skin temperatures and improves perception of the thermal state and skin wetness, producing a greater level of comfort (DeMartini et al., 2011; Webster et al., 2005) and induces beneficial effects on heart rate and VO_2 and performance (Arngrimsson et al., 2004; Tyler et al., 2015; Yeargin, Casa, McClung, et al., 2006), although some of the outcomes seem to be affected by a placebo effect described by some psychological differences (Bleakley et al., 2014; Hornery et al., 2005).

The lack of effect on tympanic temperature might be explained by the location of cooling. Distal parts of extremities have a relevant role in the heat exchange due to the location of the arteriovenous anastomoses (C. C. Bongers et al., 2016; Vanggaard et al., 2012), which leads to heat loss triggered by transferring blood to the upper parts of the skin when exercising under hot conditions. Consequently, a boost in heat conduction provokes cooled blood into returning to the core (C. C. Bongers et al., 2016; Hagobian et al., 2004).

According to our findings, some other researchers found that 10-minute, halftime cooling application didn't find any statistical differences in sweat loss, core and mean skin temperature (Duffield et al., 2003; Hornery et al., 2005) although the perceptual thermal sensation might improve the psychological aspect and benefit athlete's feeling during exercise. It's also suggested a lower oxygen consumption after a halftime cooling due to vasoconstriction of peripheral vasculature because of an increase central blood volume, helping the oxygenation of involved muscle thus gaining energy production due to the removal of blood lactate "which collaboratively benefit endurance performance by delaying the onset muscle soreness" (Hornery et al., 2005). One of the reasons why cooling at halftime may be a good option is the quantity of body fluid lost. Less fluid lost after cooling during recovery might have as a benefit a slower dehydration during a posterior exercise which may delay the presence of fatigue in muscular endurance and the capacity to maintain maximal aerobic power during exercise (Castle et al., 2006; Eijsvogels et al., 2014).

As stated in a systematic review and meta-analysis (Hohenauer et al., 2015), current results from studies comparing different cooling applications and control conditions showed significant effects reducing the symptoms of DOMS (Delayed Onset Muscle Soreness) up to 96 hours and RPE (Rate of Perceived Exertion) up to 24 hours. Also, although we didn't measure cooling effects on objective recovery characteristics such as blood plasma markers, other researches stated that lactate levels, creatine-kinase levels and blood plasma cytokines showed mainly no significant results but favored cooling compared to control conditions (Bleakley et al., 2014; Hohenauer et al., 2015; Sunderland et al., 2015).

3.6 Conclusion

The result of this study indicates that the use of a cool vest jacket for 15 minutes after a running protocol on a treadmill simulating the intensities and demands of a soccer match, changes the Ts pattern after minute 10 that enhances thermoregulatory changes on skin temperature and kept the skin temperatures of the cool vest group on significant lower values than control group. Using a cool vest during recovery after exercise in mild temperatures seems to help the body to maintain a low skin temperature that might help performance in a posterior bout of exercise, thus it may be an appropriate intervention to assist halftime recovery and benefit on posterior performance.

Chapter 4

Effects of using a Cool Vest Jacket in the Neuromuscular Function on Specific Soccer Skills

4.1 Introduction

Soccer is a team sport that involves high intensity intermittent and non-continuous actions (Bangsbo et al., 1991; Carling et al., 2008; Di Salvo et al., 2007). Players' performance will depend on a range of factors that include technical, tactical, mental and psychological factors (Bangsbo, 1994; Bradley et al., 2010; Ekblom, 1986). From a physiological perspective, the wide variety of actions performed such as passing, shooting, jumping, dribbling, direction and speed changes and adversary interaction put a great strain on several neuromuscular and metabolic parameters and will affect players' performance (Ali et al., 2007; Bangsbo, 1994; Bangsbo et al., 1991; Bradley et al., 2010; Carling, 2010; Mohr et al., 2003; Stolen et al., 2005) and the ability to complete explosive actions (Bradley et al., 2010). Throughout a match, players feel an increased fatigue, leading to a reduction in the ability to perform high intensity actions (Mohr et al., 2003) and the capacity of producing peak force rates (Rahnama et al., 2003). Thus, it is proven that performance in specific velocity activities (Andersson et al., 2008; Drust et al., 2005; P. Krustrup et al., 2006; P. Krustrup et al., 2010; Magalhaes et al., 2010; Mohr et al., 2003; Mohr et al., 2004; J. Oliver et al., 2008; J. L. Oliver et al., 2007) and jumping (Andersson et al., 2008; Magalhaes et al., 2010; J. Oliver et al., 2008; J. L. Oliver et al., 2007) are reduced immediately after a match. This decreasing has been attributed to the reduction of maximal force and power levels due to fatigue accumulation (Enoka et al., 1992; Gandevia, 2001; Mohr et al., 2005).

Fatigue influence among soccer player's physical abilities has been widely studied with investigations that assume a reduction on them after 45 minutes of specific exercise (Carling, 2010; Carling et al., 2008) and at the end of real and simulated matches (Mohr et al., 2003; Rahnama et al., 2003). Thus, a reduction of the capacity to complete soccer specific abilities during the second half of a match is proved (Mohr et al., 2003; Rampinini, Coutts, et al., 2007; Rampinini et al., 2009), especially the amount of sprints, high intensity races and the total distance covered related to the first half of the same match (Bangsbo, 1994; Bangsbo et al., 1991), also assuming decreases on maximal force levels, jump capacity and sprint performance (Andersson et al., 2008; Ascensao et al., 2008; P. Krustrup et al., 2010; Thorlund et al., 2009). Despite an increase of all these signs during the last 15 minutes of the match, some studies suggest a decrease of the intensity level on the initial 15 minutes of the second half compared to the first half (Mohr et al., 2003; Rampinini, Coutts, et al., 2007).

Some reasons can explain a reduction in performance throughout a match: metabolic causes such as muscle acidosis, lactate accumulation or depletion of creatine phosphate stores (P. Krustrup, Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., Bangsbo, J., 2003) or due to central nervous system during heat conditions (Meeusen et al., 2006; Nybo, 2008; Nybo & Nielsen, 2001).

Core temperature is an element that seems to be affected in performance modification (Cheung et al., 2004; Ekblom, 1986; Lovell et al., 2007; Mohr et al., 2004; Nybo, 2008). Increasing core temperature appears to reduce the capacity to perform high intensity exercises (Bergh et al., 1979; Drust et al., 2005; Houmard et al., 1991; Sargeant et al., 1987; Stewart et al., 1998) and mid-long duration endurance activities (Gonzalez-Alonso, Teller, et al., 1999; Nybo & Nielsen, 2001). During a soccer match, average core temperature fluctuates between 39° and 39.5° (Ekblom, 1986; Mohr et al., 2004) although, some participants have reached individual values over 40°, which can result in a deterioration of the cerebral function (Nybo & Nielsen, 2001).

To those effects, body cooling is a method which could benefit the cardiovascular system (blood distribution to implied muscles), metabolism (preserving an optimal temperature for the enzymatic activities) and central and peripheral nervous system (suppressing of inhibition neuronal signals of central system) (Duffield et al., 2007; Marino, 2002) changing sensorial feed-back of thermoregulatory system, resulting in an attenuation of the protection of the central nervous system mechanisms controlling core temperature overload (Carling et al., 2008; Castle et al., 2006). These factors enhance the necessity of using different cooling methods before and during the exercise, as a strategy to reduce rising core temperature negative effects (Castle et al., 2006; DeMartini et al., 2011; Drust et al., 2000; Duffield, 2008; Duffield et al., 2003; Marino, 2002). Some methods usually used are cool jackets (Hunter et al., 2006; Lopez et al., 2008; Price et al., 2009), cool compresses (Walker, 2004), face and head coolers (Rasch et al., 1993), water-sprays (Weiner et al., 1980) and cold water immersion (Demartini et al., 2015).

Some studies suggest that cooling benefits are effective up to 30-40 minutes (Drust et al., 2000; Hessemer et al., 1984; D. T. Lee et al., 1995), proving the performance improving in endurance sports (Arngrimsson et al., 2004; Hasegawa et al., 2005; Hunter et al., 2006; Stannard et al., 2011; Uckert et al., 2007). These findings encourage the idea that cooling could be an interesting method to recover strength baseline levels, during match's half time, in team sports like soccer (Bogerd et al., 2010; Duffield, 2008; Price et al., 2009).

Therefore, given the soccer specific necessities, the purpose of the present study was to investigate the effects of a cool vest used as a cooling method during the half part of a simulated soccer match within the neuromuscular function of soccer players.

4.2 Methodology

Participants

Nineteen healthy males, recreational players [age 21.9±1.7 years, height 177.4±5.4, body mass 23.28±1.9, peak oxygen consumption (VO2max) 57.4±3.1 mL/Kg/min) participated in this study. The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. The protocol was made according the ethical principles of The World Medical Association's Declaration of Helsinki of 1986. For a period of 48 h before each trial, the participants were instructed to refrain from strenuous exercise. Furthermore, the participants were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before each trial. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials. The subjects received no economic reward for their participation in the study and had no previous injury in the 6 months prior to the study too.

Cooling Garments

Cool Vest is made of neoprene and has twelve pockets for ice packs, eight on the chest and stomach and four over the back. The ice packs were stored for a minimum of 6 hours in a conventional freezer. The cool vest was worn directly on top of the participants' clothing as they rested in a seated position. Participants wore the same clothing during the trial (running and soccer shoes, sports socks and a soccer shirt).

Experimental Procedure

The participants were randomly assigned in two groups depending if they were wearing the Cool vest jacket during recovery or not. To select participants with similar cardiovascular levels, all undertook a preliminary Cooper test (Cooper, 1968) on a track and field facility two weeks before to estimate their VO2 peak.

During the first visit to the laboratory, each participant's height, body mass and skin (Iberia PCE-891) and tympanic (Ri-Thermo® N.) temperature were measured. Afterwards participants completed "The 11+" warm-up protocol form F-MARC proposed and validated by FIFA (Bizzini et al., 2015; F-MARC, 2013). Then three neuromuscular tests were performed by the participants with a resting time of at least 60 seconds among attempts (Bogdanis et al., 1998) and 3 minutes among each different test (Fukuda et al., 2011; Fukuda et al., 2012). Tests consisted of a shot speed test, registered with a Stalker Pro® radar, to a goal at a 2 meters' distance, considering that more distance could be detrimental to shot power, a Countermovement Jump (CMJ) was evaluated with a contact platform (Chronojump) starting from a standing position, then squatting down to a knee angle of 90° degrees and finally extending the knee and jumping in 1 continuous movement. Arms were kept on the hips to minimize the upper body contribution. The position of the upper body was standardized to avoid flexion and extension of the trunk and a 30-meter sprint recording the maximum peak velocity with a Stalker Pro radar and the maximal speed using infrared photoelectric cells (Artek® PNP) positioned at the ear's height of each participant.

The intermittent protocol undertaken employed repeated 9 min bouts of exercise based on Spanish soccer players match analysis data derived and adapted from (Di Salvo et al., 2007), and reflecting the typical time spent in each of the respective activity levels. The speeds for each level were 6.5, 12.5, 16.5, 21 and 23 km/h, representing 63%, 14%, 15%, 5% and 3% of the protocol duration, respectively. The same speeds were employed for each participant as all them achieved similar levels of VO2max. The levels categories were organized in an acyclical manner in an attempt to reflect the nature of a 45-min soccer match play. Unfortunately, the use of a motorized treadmill precluded the inclusion of true sprinting and backwards and sideways activities. Participants then rested in a seated position for the 15-min simulated half time. Recovery involved either no cooling or the application of an ice-cooling vest. After the intermittent protocol and the resting time, the participants performed the same neuromuscular tests in the same order as before.

4.3 Statistical Analysis

Results are expressed as mean values ± SD. Because homoscedasticity and normal distribution of the data were verified by means of Levene's and Shapiro-Wilk test, parametric statistics were used. Intervention was analysed using a two-way analysis of variance with repeated measures on both groups: resting with and without cool vest and two different moments, after the warm-up and following the intermittent protocol and the 15-minute seated resting. Independent T-Test were also used to find out the differences within groups. The statistical significance was set at $p<0.05$ for all analyses. All data was analyzed using SPSS (Version 23.0.0, Chicago, IL, USA) and Microsoft Excel 2013 (2015, Microsoft Corporation).

Figure 13. *Running Protocol on treadmill*

Figure 14 *Countermovement Jump (CMJ)*

Figure 15. *30-meter sprint. Photocells and Radar.*

Figure 16. *Shoot speed test using the Radar*

4.4 Results

The results for mean ± SD CMJ, Shot Speed and 30-m sprint time and maximal speed and % decline for the first and second test respectively, for all conditions are presented in Table 1.

Table 5. Effect of cool vest recovery method on CMJ, Speed Shot, 30 meters sprint total time and 30 meters maximal speed (mean ± sd) P obtained with a two-way anova. Interaction between moments and groups.

	Control Group	Cool Vest Group	F	p
Pre-test CMJ (cm)	36,18 ± 6,52	37,49 ± 5,29	0.330	0.573
Post-test CMJ (cm)	35,54 ± 6,22	37,25 ± 5,11		
Pre-test Shot Speed (km/h)	89,13 ± 7,75	92,47 ± 5,62	6.746	0.019*
Post-test Shot Speed (km/h)	86,63 ± 7,58	92,73 ± 4,12		
Pre-test 30-m Sprint (s)	4,58 ± 0,24	4,46 ± 0,20	0.183	0.674
Post-test 30-m Sprint (s)	4,74 ± 0,36	4,57 ± 0,26		
Pre-test 30-m Maximal Speed (km/h)	30,06 ± 1,84	29,55 ± 1,77	0.585	0.456
Post-test 30-m Maximal Speed (km/h)	29,75 ± 2,84	30.01 ± 1,51		

Countermovement Jump Test

After the intermittent protocol and compared with baseline, neither control group nor cool vest group had significantly reduced their performance (p=0.531). There were some non-statistically significant variations in height after the intermittent protocol for control group (36.17±6.52 to 35.54±6.22; p=0.358) reducing a 1.74% meanwhile Cool-Vest group height was reduced too (37.48±5.28 to 37.25±5.11; p=0.526), reducing their jump height less than control group, 0,61%.

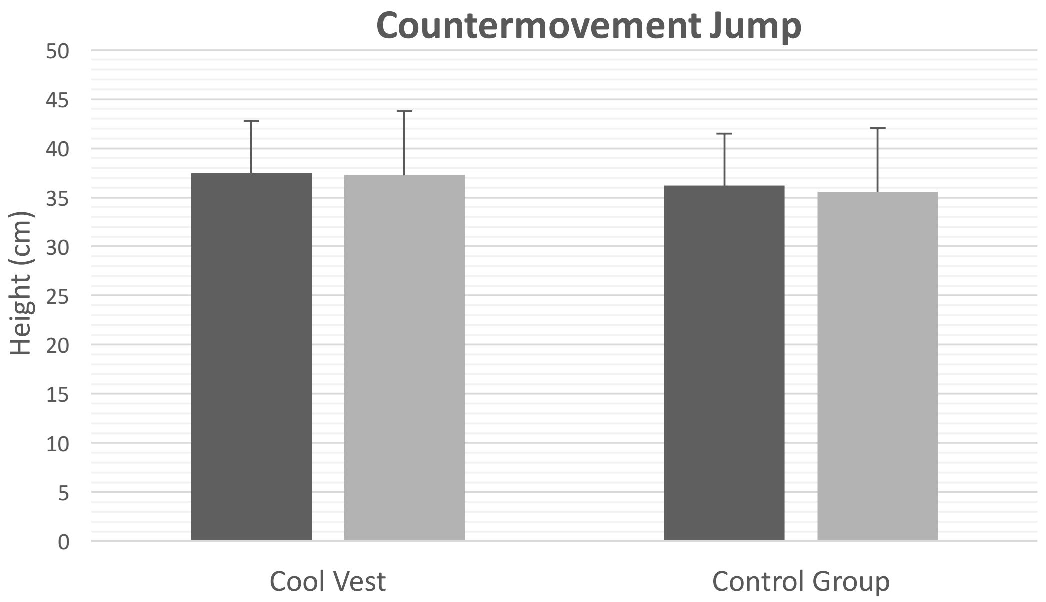


Figure 17. Pre and Post CMJ results

Shot Speed Test

Shot speed results showed a different tendency than CMJ. Control group shot speed was significantly reduced 2.8% (89.12 ± 7.74 to 86.62 ± 7.58 p=0.003) in contrast to Cool Vest group whom maintained their performance increasing their results only a 0,29% (92,46 ± 5,61 to 92,73 ± 4,11 p=0.806). Significant differences were found between conditions p=0.043.

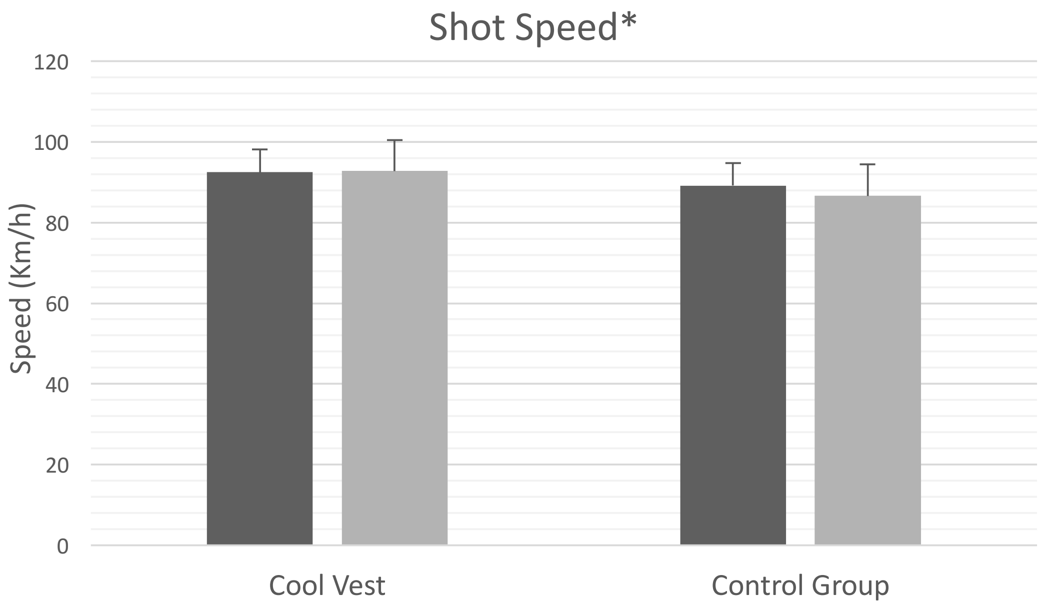


Figure 18. Pre and Post shot speed results. * p<0.05

30m Sprint Speed and Maximal Speed Test

30m-sprint speed time compared with initial values, was reduced a 3,49% in Control group (4.58 ± 0.23 to 4.74 ± 0.36 p=0.160) whereas Cool Vest group reduced its performance a 2.24% from baseline (4.56 ± 0.25 to 4.46 ± 0.19 p=0.146). No significant values were found between groups afterwards the intermittent protocol p=0.254.

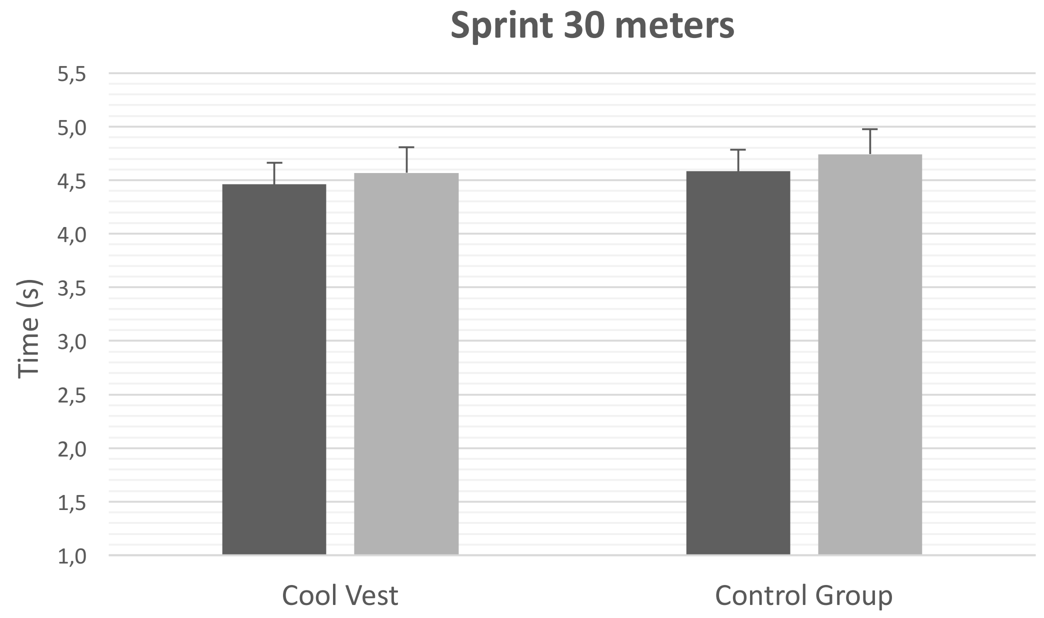


Figure 19. Pre and Post 30-meter sprint results

Maximal speed reached during the 30m-sprint test had a different outcome than sprint time. Control group decreased their velocity 1.03% (from 30.06 ± 1.84 to 29.75 ± 2.84 p=0.694) however Cool Vest group increased their maximal velocity a 1.52% (29.55±1.77 to 30±1.51 p=0.507). No significant differences were obtained from maximal speed test p=0.813 between groups.

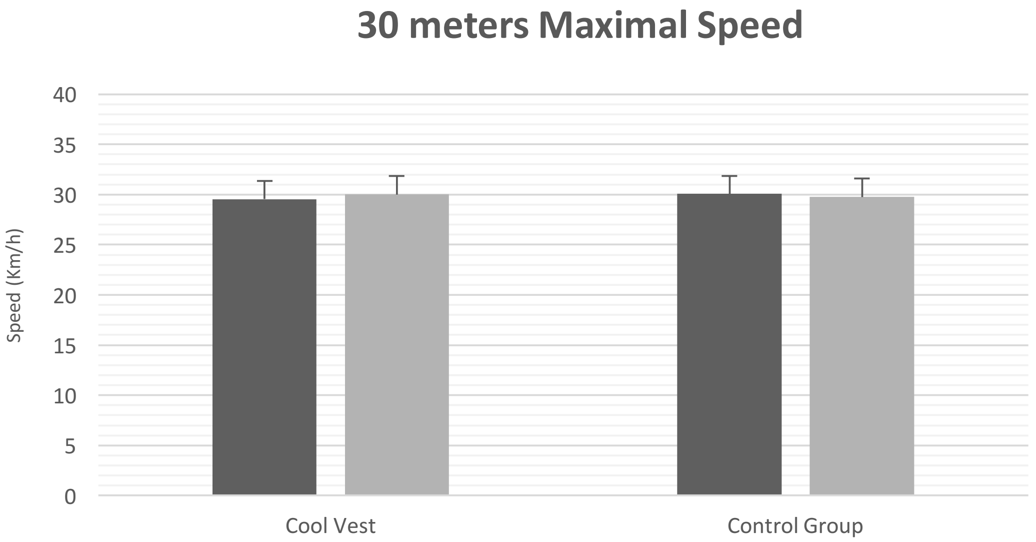


Figure 20. Pre and Post CMJ results

4.5 Discussion

One of the aims of the current study was to investigate the effects of a cool vest used as a cooling method during the half part of a match within the neuromuscular function of soccer players. We observed a fatigue-induced effect on all three neuromuscular tests conducted from baseline values to post-exercise values, decreasing 30m sprint, CMJ and Shot Speed abilities, but only one of them, the shoot speed test, had a significant statistic result.

In our study, we observed how sprint ability was altered at the end of the intermittent protocol. This finding corroborated those of Andersson et al. (2008), who found a 3%-time reduction during 20-m sprint after a 90-minute soccer game. Also, in accordance with the same study, we found that control group 30-m sprint was 3.49% slower, the same thing happened to cool vest group with a reduction of 2.24% of its baseline values, which is not a significant value (p=0.254). Within the same test, we also recorded maximal speed, finding that control group decreased their velocity a 1.03% and cool vest group increased their maximal velocity a 1.52%. Differences were not significant either (p=0.813). According to Robineau et al. (2012) knee extensor and flexor strength decrements seemed to be responsible for this running speed alteration. Indeed, elite soccer players demonstrated a strong correlation between quadriceps muscle strength and sprinting speed (Wisloff et al., 2004). Thus, this reduction of maximal velocity and sprint ability due to the fatigue post-exercise could be attributed either to a decrease of stride frequency (Robineau et al., 2012) or to stride amplitude or foot contact time (Small et al., 2009).

Control group had a CMJ reduction of 1.74% and cool vest group a 0.61%. Our values showed a different magnitude to 4% decline in CMJ that have been previously reported (Bangsbo, 1994; P. Krustrup et al., 2006; Reilly et al., 1979). This discrepancy could be partly explained by the difference between a real game and our intermittent protocol in a treadmill, and because their values are from a 90-minute match. Otherwise we found similar results in CMJ during a 90-minute neuromuscular induced fatigue remaining CMJ values almost unchanged, affirming that CMJ performance is not greatly affected by a soccer match (Robineau et al., 2012). Even though differences are minimum between groups, cool vest group had a lower reduction of their baseline values.

On the other hand, we observed that shooting performance was reduced under fatigue condition. In our study, control group decreased a 2.8% their shoot speed, according to some studies that observed a reduced coordination between upper and lower leg after 6 minutes of stepping exercise and thus, a reduction of shot speed (Kellis et al., 2006). Furthermore, the assessment of shooting speed before and after 90 minutes of soccer-specific exercise led to initial reports that shooting performance was maintained following exercise (Ali et al., 2007), supporting the significant difference between groups ($p=0.043$) that cool vest group increased 0.29% their shot speed performance afterwards the intermittent protocol.

One of the reasons that could explain this increasing could be that parasympathetic nerve activity was accelerated due to the stimulation of cold receptors (Buchheit et al., 2009). As seen in some other researches with cool vests (Brade et al., 2010; Lopez et al., 2008), results were not significant between groups, but the outcome was favourable to cool vest group for all three tests. This assumption confirms the same results of some other studies investigating intermittent-sprint performance (Drust et al., 2000; Duffield et al., 2003), and finding non-significant benefits on their results. Furthermore, exercise protocols allowing sufficient recovery (>60s) and repletion of Phosphate creatine stores between attempts (Bogdanis et al., 1998), which may result in limited declines in performance and thus limited precooling ergogenic benefits (Duffield et al., 2003).

We have found no decrement on performance on any of the variables measured. All tests and fatigue protocol were taken under a normothermic ambient conditions lab (22°), which makes the possibility of an athlete reaching a critical core temperature of above 39° more difficult (Ekblom, 1986; Mohr et al., 2004; Nybo & Nielsen, 2001). Thus, a cool vest jacket used under ambient temperature conditions might be useful to attenuate the effects of fatigue at a game's halftime, having no detrimental effects that might affect a subsequent performance. Some studies have demonstrated that some cooling techniques such as cold water immersion or whole body cryotherapy have analgesic effects on muscles lowering their temperature (Costello et al., 2012; Costello et al., 2014) resulting in a reduced contraction capacity (P. Krustrup et al., 2006; Mohr et al., 2004) and range of movement (Bleakley et al., 2013), increased joint stiffness (Sargeant et al., 1987) or a decreased neuromuscular response of knee and ankle (Macedo Cde et al., 2016; Macedo et al., 2014), increasing the risk of injury (Csapo et al., 2017).

Nevertheless, the cool vest as a recovery method might strengthen its benefits when applied after exercise in the heat (Castle et al., 2006; Duffield, 2008; Duffield et al., 2003; Duffield et al., 2007; Gonzalez-Alonso, Teller, et al., 1999; Lopez et al., 2008; Marino, 2002; Price et al., 2009) and when used for mid-long endurance exercise (Arngrimsson et al., 2004; Hasegawa et al., 2005). Despite this a greater benefit may occur in game situations with more frequent and longer rest intervals, which could allow for significant decreases in body temperature (Duffield, 2008).

4.6 Conclusion

In conclusion, the effects of the cool vest as cooling method during the recovery time did not significantly maintain or improve the baseline values of neuromuscular tests we applied, compared with control group. However, slightly better values were found in cool vest group. Furthermore, applying the cool vest for longer or until as close as possible to the exercise should be more beneficial for endurance and sub-maximal activity like soccer. The ergogenic benefits of effective cooling procedures for team-sports neuromuscular activities are not significantly maintained compared with control group and baseline values. Further research is needed with a real match as a fatigue inducing protocol instead a protocol in a treadmill, which has a lack of jumps, change of direction, ball action and adversary interaction.

Chapter 5

Effects of the Cool Vest Jacket on Skeletal Muscle Contractile Properties Response with Tensiomyography

5.1 Introduction

Soccer is a demanding sport that includes high intensity intermittent actions such as jumps, accelerations and decelerations and change of direction during consecutive days involving training and matches (Bangsbo, 1994; Bizzini et al., 2015; Mohr et al., 2005; J. L. Oliver et al., 2007). All these physical demands lead to a physiological strain on muscles causing a decrease on performance during the subsequent practices or games. The capacity to recover between training sessions or halves of a match is a crucial aspect to improve performance and minimize the risk of possible injuries (Reilly et al., 2005).

Exhausted muscles are not able to absorb energy leading to a decrease on knee flexion angle (Chappell et al., 2005) and forcing other structures, such as ligaments, to absorb the energy (Mair et al., 1996). Lower extremity muscle fatigue may impair the capacity of the dynamic knee defence mechanisms. Deficiencies of neuromuscular control in the lower extremities due to strenuous exercise alters knee-flexion angle and moments, hip internal rotation, and knee-abduction angles and moments (Chappell et al., 2008; McLean et al., 2007).

Active trunk flexion during landing situations produce increments in knee and hip flexion angles, if the knee moves into more flexion during the loading phase of a landing, the anterior tibial shear force decreases (Beynnon et al., 1992). During soccer, quadriceps play an important role in jumping and ball kicking. Also, the hamstring muscles are considered to act as a synergist of the Anterior Cruciate Ligament (ACL), stabilizing the knee during turns or tackles (Fried et al., 1992). This group of muscles protect the ACL during movements involving tibia translation due to an existing reflex arc between the ACL and the hamstrings under functional conditions (Beard et al., 1993; Friemert, Bumann-Melnyk, et al., 2005; Friemert, Faist, et al., 2005). The quadriceps and hamstrings muscles are able to load or unload the knee ligaments based on their coordinated activation, quadriceps induce tension and strain to ACL (Beynnon et al., 1992) and hamstrings creating a posterior orientated force (Colby et al., 2000), counteracting the anterior shear force that strains the ACL. The co-contraction of theses muscles might reduce the excessive forces applied when the knee is more flexed (>15° of knee flexion) (Li et al., 1999). Knee stability depends on both passive and active restraints to tibiofemoral motion. Due to physical activity, knee laxity seems to be increased (Grana et al., 1988; Skinner, Wyatt, Stone, et al., 1986; Steiner et al., 1986; Weisman et al., 1980). Restraining the dynamics of the knee can prevent or lessen injury during exhausting exercise.

Some observational studies state that injuries such as those involving the ACL occur approximately within 40 milliseconds after initial contact (Koga et al., 2010; Krosshaug et al., 2007; Olsen et al., 2004). Muscular contraction time during the preparatory phase before initial contact seems a valuable parameter to investigate due to its relation with neuromuscular fatigue.

The elevation of core temperature is a neuromuscular fatigue inducer and is associated with alterations in central and peripheral function (Martin et al., 2005; Tucker et al., 2004). Hyperthermia affects whole-body exercise performance due to the reduction of voluntary activation of skeletal muscle (Cheung, 2007; Drust et al., 2005; Mohr et al., 2006; Nybo, 2008; Nybo et al., 2004; S. Racinais et al., 2012), muscle contractile function (Morrison et al., 2004) affects to perceptual mechanisms (Nybo, 2008; Nybo et al., 2004; S. Racinais et al., 2012) and anticipatory and decision-making responses (Besier et al., 2001; Houck et al., 2006; Tatterson et al., 2000), increasing muscle activation time and ground time contact (Besier et al., 2001; Borotikar et al., 2008).

Body cooling is a method which could benefit the cardiovascular system (muscle blood flow), metabolism (preserving an optimal temperature for the enzymatic activities) and central and peripheral nervous system (suppressing of inhibition neuronal signals of central system) (Duffield, 2008; Marino, 2002), changing sensorial feed-back of thermoregulatory system, and enhancing the necessity of using cooling methods before and during the exercise, as a strategy to reduce rising core temperature negative effects (Castle et al., 2006; Drust et al., 2000; Duffield, 2008; Duffield et al., 2003; Hessemer et al., 1984; D. T. Lee et al., 1995; Marino, 2002). Some methods used have been: cool jackets (Hunter et al., 2006;

Lopez et al., 2008; Price et al., 2009), cool compresses (Walker, 2004), face and head coolers (Rasch et al., 1993), water-sprays (Weiner et al., 1980) and cold water immersion (Binkley et al., 2002; Clapp et al., 2001). Cold therapy has been able to relate the improvement in performance or perceptual recovery to physiological, immunological, haematological or neuromuscular mechanisms (Pointon et al., 2012). More specifically, data on the efficacy of cold therapy on neuromuscular recovery is limited (Peiffer et al., 2010).

Some researchers suggest that cooling benefits are effective up to 30-40 minutes (Drust et al., 2000; D. T. Lee et al., 1995), proving performance improvement in endurance sports (Arngrimsson et al., 2004; Hasegawa et al., 2005; Hunter et al., 2006; Stannard et al., 2011; Uckert et al., 2007) and voluntary force and intermittent-sprint performance in the heat (Minett et al., 2011). This encourages the idea that in team sports like soccer, during match's half time, cooling could be an interesting method to recover strength baseline levels (Bogerd et al., 2010; Duffield et al., 2003; Price et al., 2009).

Therefore, the purpose of the current study was to determine the effects of a cool vest jacket, if any, used as a recovery method during 15-minutes of passive, seated recovery (simulating half time of a soccer match) after a fatigue induced protocol on the biceps femoris (BF) contraction time response. This was done on the basis of the theory that body cooling may reduce the fatigue induced ACL strain risks.

5.2 Methodology

Participants

A total of 30 healthy males, recreational players were assessed. Their characteristics were as follow (mean ± SD): age, 22.27 ± 2.78 years; body weight mass, 71.67 ± 7.27 kg; body height 176.12 ± 7.44 cm; body mass index 23.08 ± 3.13; peak oxygen consumption (VO2max) 58.18 ± 2.7 mL/Kg/min. The experimental procedures were verbally explained in detail, and written informed consent was obtained from all participants prior to the study. This study was designed according to the standards of Bioethics committee of the University of Barcelona and according to the principles of the Declaration of Helsinki of 1975, reviewed on 2008. The participants referred not having any injury in the 6 months prior to the study. For a period of 48 h before each trial, the participants were instructed to refrain from strenuous exercise. Furthermore, the participants were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before each trial. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials. The subjects received no economic reward for their participation in the study.

Study Design

We used a repeated-measures design. Participants performed a preliminary trial to estimate their VO2max, the Cooper Test (Cooper, 1968) on an athletic track two weeks before the experiment. The whole study was conducted on a single day. During the participant first visit to the laboratory, weight, statures, skin and tympanic baseline temperature were measured. Then, participants completed a self-paced warm-up. After they performed a Drop Vertical Jump (DVJ), contractile properties were evaluated and afterwards they undertook 45-minutes of an intermittent running protocol on a motorized treadmill and 15 minutes of passive, seated recovery (simulating half time). Both tests prior to the running protocol were randomized in order to avoid any fatigue effects that could affect the outcomes due to a possible activation of inhibitor effect on muscle contraction. Finally, they performed the same tests as before. The exercise sessions took place in a laboratory chamber at a temperature of 22±1.9°C and

30±4% relative humidity.

Cooling Garments

Cool Vest is made of neoprene and has twelve pockets for ice-packs, eight on the chest and stomach and four over the back. The ice packs were stored for a minimum of 6 hours in a conventional freezer. The cool vest was worn directly on top of the participants' clothing as they rested in a seated position. Participants wore the same clothing during the trial (running shoes, sports socks and a T-shirt).

Mechanical Properties of Muscle Evaluation

Response contraction time and amplitude throughout maximal passive twitch contractions were recorded using tensiomyography (TMG). With this technique, oscillations of the stomach muscles are generated in response to a percutaneous electrical stimulation. These oscillations were recorded at the skin surface using a spring-loaded displacement sensor positioned perpendicularly directly above the centre point of the muscle to enable sensitive recording of mechanical displacement of the underlying muscle tissue. A host online computer at a sampling rate of 500 Hz recorded this displacement. A single square wave monophasic maximal 1 millisecond pulse was applied to elicit a twitch response of the muscle that was recorded by the displacement sensor. To obtain maximal mechanical response the stimulation was increased by 10 mA with an interval frequency of 10 seconds to minimize the effects of fatigue and potentiation. The stimulation was increased gradually until no further displacement of the stomach muscles could be produced. The positions of the sensor and the electrodes were marked with a dermatological marker pen in order to replicate the positioning for the subsequent test used for the reliability measures.

Seven parameters were extracted from each measurement: maximal displacement amplitude (Dm), delay time (Td) contraction time (Tc), sustain time (St) and half relaxation time (Tr) as proposed by Valencic (1990). Maximal displacement amplitude (Dm) was defined as the peak amplitude in the displacement–time curve of the tensiomyographical twitch response. Delay time (Td) was defined as the time between the electrical stimulus and displacement of the sensor to 10% of Dm; Contraction time (Tc) was the time from 10% to 90% of Dm was reached; Sustain time (St) was defined as time displacement was above 50% of Dm; and Half relaxation time (Tr) was the time from 90% Dm to decline to 50% of the Dm in the relaxation phase (Simunic, 2012). Also, two more values were recorded as seen in some other researches (Garcia-Manso et al., 2011) (Rey et al., 2012) because of their higher precision and sensitivity, Velocity of Muscle Deformation (Vd) at the onset of contraction (10% Dm) and the velocity of the mean contraction (Vc) observed between 10% Dm and 90% of Dm (Fig. 1).

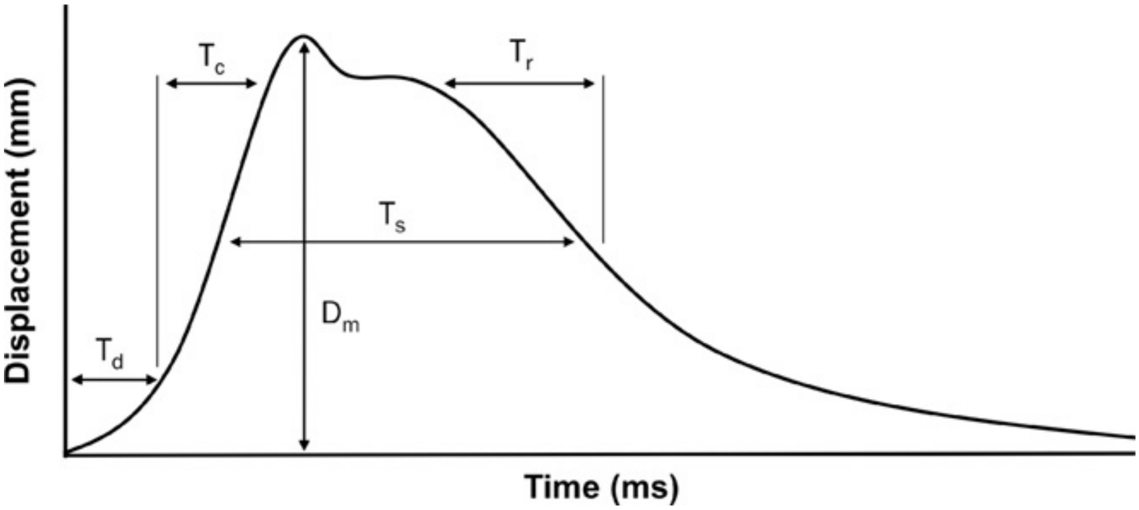
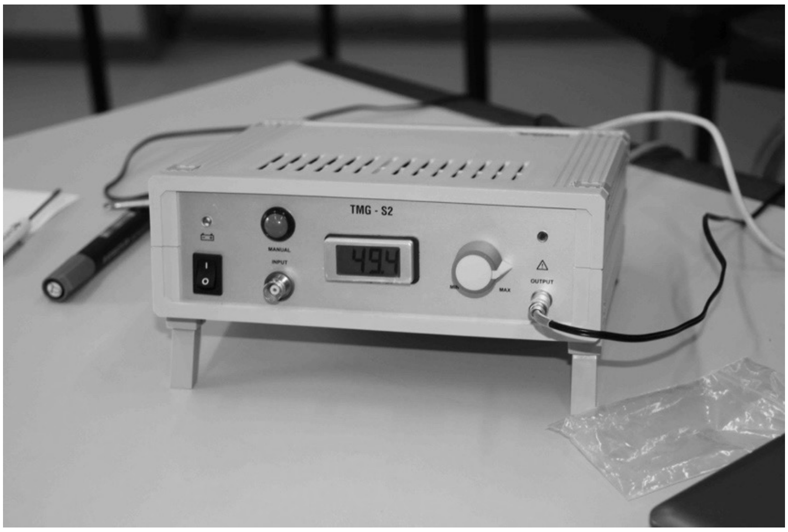


Figure 21. TMG parameters: Dm: maximal displacement; Tc: contraction time; Td: delay time; Tr: half-relaxation time; Ts: sustain time.

Experimental Procedure

During the first visit to the laboratory, each participant's height, body mass and skin (Iberia PCE-891) and tympanic (Ri-Thermo N.) temperature were measured. Afterwards participants completed a 15-minute warm-up including 8 minutes of self-paced treadmill running, and arm and legs stretching and maximal CMJ. Then, three DVJ's were performed by the participants with a resting time of at least 60 seconds between attempts (Bogdanis et al., 1998). Starting stood with their feet shoulder width apart on a 40cm high box the participants were instructed to drop off the box, reach a 90-degree knee angle and perform a maximal jump after landing. After that, dominant-leg biceps femoris (BF) contractile properties were assessed by means of a tensiomyograph (TMG). Measurements were performed in a prone position on a padded bench with a foam pad below the leg to maintain a knee angle around 20 degrees. A digital displacement transducer (GK 40, Panoptik d.o.o., Ljubjana, Slovenia) which incorporates a spring of 0.17 N m-1, was placed perpendicular to the stomach muscles of the shooting leg BF. Sensor location was determined anatomically according to Perotto (Perotto et al., 2005). Once chosen, this position was marked with a dermatological pen to ensure the sensor was placed in the exact same position on subsequent measurements. Self-adhesive bipolar electrodes (Compex Medical SA, Ecublens, Switzerland) were placed symmetrically 5 cm distal and proximal to measuring point. Stimulation pulse was 1 ms wide delivered from a TMG-S2 (EMF-FURLAN& Co. d.o.o., Ljubljana, Slovenia) stimulator which was applied through the skin surface to elicit a twitch response recorded by the displacement sensor. To obtain maximal mechanical response the stimulation started at 30 mA and was increased by 10 mA at a frequency of 10s intervals to avoid the effects of fatigue and potentiation of a muscle (Krizaj et al., 2008). The stimulation was increased gradually until no further displacement of the stomach muscles could be produced.



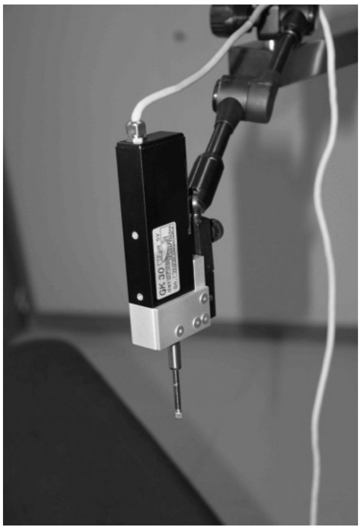


Figure 22. Tensiomyograph and displacement transducer.

The intermittent protocol undertaken employed repeated 9 min bouts of exercise based on Spanish soccer players match analysis data derived and adapted from Di Salvo (Di Salvo et al., 2007) and reflecting the typical time spent in each of the respective activity levels. The speeds for each level were 6.5, 12.5, 16.5, 21 and 23 km/h, representing 63%, 14%, 15%, 5% and 3% of the protocol duration, respectively. The same speeds were employed for each participant as all them achieved similar levels of VO2peak. The category levels were organized in an acyclical manner in an attempt to reflect the nature of a 45-min soccer match play. Unfortunately, the use of a motorized treadmill precluded the inclusion of true sprinting and backwards and sideways activities. Participants then rested in a seated position for the 15-min simulated half time. Recovery involved either no cooling or the application of an ice-cooling vest.

After the intermittent protocol and the resting time, participants performed the same tests in the same order as before.

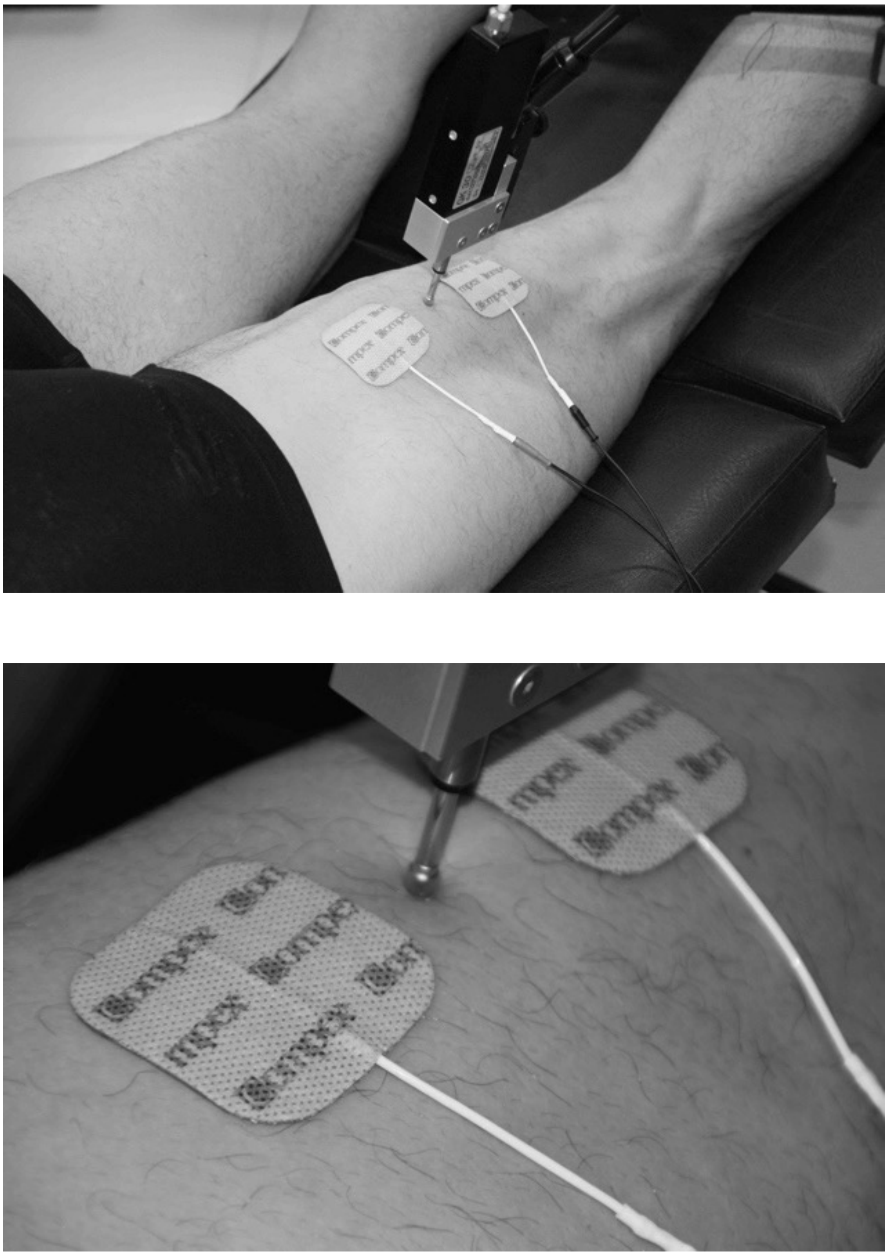


Figure 23. Example of the sensor and electrodes location to measure biceps femoris response contraction

5.3 Statistical Analysis

Results are expressed as mean values ± SD. Because normal distribution of the data was verified by means of Levene's and Kolmolgorov-Smirnov test, parametric statistics were used. Intervention was analysed using a two-way analysis of variance with repeated measures on both groups: resting with and without cool vest and two different moments, after the warm-up and following the intermittent protocol and the 15-min seated resting. Independent *t*-tests were performed to identify significant differences between cool vest and control group after the recovery period. Statistical significance was set at $p<0.05$ for all analyses. All data was analyzed using SPSS (Version 23.0.0, Chicago, IL, USA).

5.4 Results

Muscle contraction response outcomes changed before and after the intermittent protocol and the use of the cool vest jacket are shown in Table 1 as means and SD.

Maximum Amplitude of Muscle Deformation (Dm)

Muscle deformation presented a statistically significant different outcome (F=4.690 p=0.039) compared with baseline levels in both groups, cool vest and control group. The t-test showed that control group reduced muscle deformation a 10.73% (6.52±2.27 mm to 5.82±1.96 mm, t=2.054 p=0.059) meanwhile cool vest group increased a 3.51% (6.83±1.06 mm to 7.07±1.40 mm, t=0.543 p=0.596).

Contraction Time (Tc)

Contraction time showed no statistical difference between conditions. Both groups increased the time to reach the 90% maximal deformation. Control group a 3.85% and cool vest group a 12.80%. This difference may be related to muscle displacement, considering that control group reduced their maximal deformation and cool vest group increased it.

Velocity of contraction displacement (Vc)

Velocity of contraction revealed statistically significant values between groups (F=4.589 p=0.041) and moments (F=11.873 p=0.002). The control group reduced their velocity of contraction a 13.25%, and the cool vest group decreased 7.10%.

Delay time (Td)

Delay time between the stimulus and 10% of Dm showed no statistical differences between groups, although the control group reduced that time by 0.29% and cool vest group increased it by 2.25%.

Velocity of initial contraction deformation (Vd)

There were also significant differences between groups (F=13.662 p=0.001) and moments (F=4.270 p=0.048) on the contraction velocity between the stimulus and 10% of Dm, the control group velocity reduced by 7.40% and reaction velocity of cool vest group remained almost the same as baseline increasing by 0.01%.

Time displacement (Ts) above 50% of Dm also showed differences between groups (F=4.908 p=0.035) same as Half relaxation time (Tr) showing differences between the different moments the measures were taken (F= 7.346 p=0.011).

Table 6. Means and standard deviations of the variables T_c, D_m, V_c, S_t, T_r, T_d, and V_{d10} before and after the intermittent protocol of cool vest and control group and experimental.

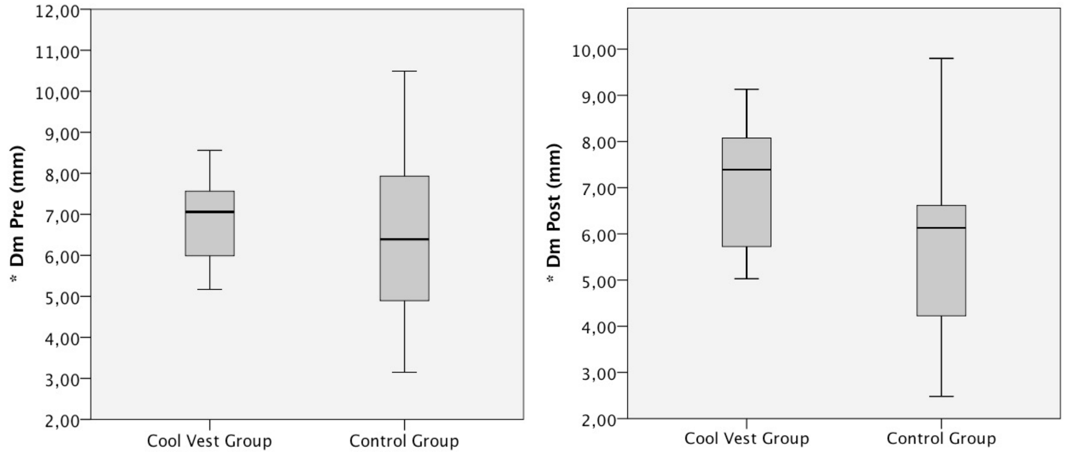
				Signification		
Variable	Group	PRE	POST	Principal Effects	F	p
Tc (ms)	Control	35.76 ± 8.78	37.14 ± 2.18	Time	3.824	0.061
	Cool Vest	33.20 ± 6.12	37.45 ± 2.63	Group	0.168	0.683
				Interaction	0.993	0.328
Dm (mm)	Control	6.52 ± 2.27	5.82 ± 1.96	Time	1.144	0.294
	Cool Vest	6.83 ± 1.06	7.07 ± 1.40	Group	1.717	0.201
				Interaction	4.690	0.039*
Vc (mm/ms)	Control	0.181 ± 0.046	0.157 ± 0.044	Time	11.872	0.002*
	Cool Vest	0.211 ± 0.046	0.196 ± 0.049	Group	4.589	0.041*
				Interaction	0.727	0.401
St (ms)	Control	175.34 ± 26.42	176.92±60.92	Time	3.452	0.074
	Cool Vest	201.50 ± 30.35	188.36±30.56	Group	4.908	0.035*
				Interaction	0.993	0.750
Tr (ms)	Control	61.34 ± 15.77	56.69 ± 16.43	Time	7.346	0.011*
	Cool Vest	82.08 ± 29.92	67.26 ± 28.06	Group	3.306	0.080
				Interaction	1.736	0.198
Td (ms)	Control	23.37 ± 2.41	23.30 ± 2.27	Time	0.450	0.508
	Cool Vest	23.11 ± 1.68	23.63 ± 2.16	Group	0.001	0.980
				Interaction	0.569	0.457
Vd (mm/ms)	Control	0.027 ± 0.009	0.025 ± 0.008	Time	13.662	0.001*
	Cool Vest	0.029 ± 0.005	0.029 ± 0.005	Group	4.270	0.048*
				Interaction	0.293	0.593

Values are presented as mean +- SD

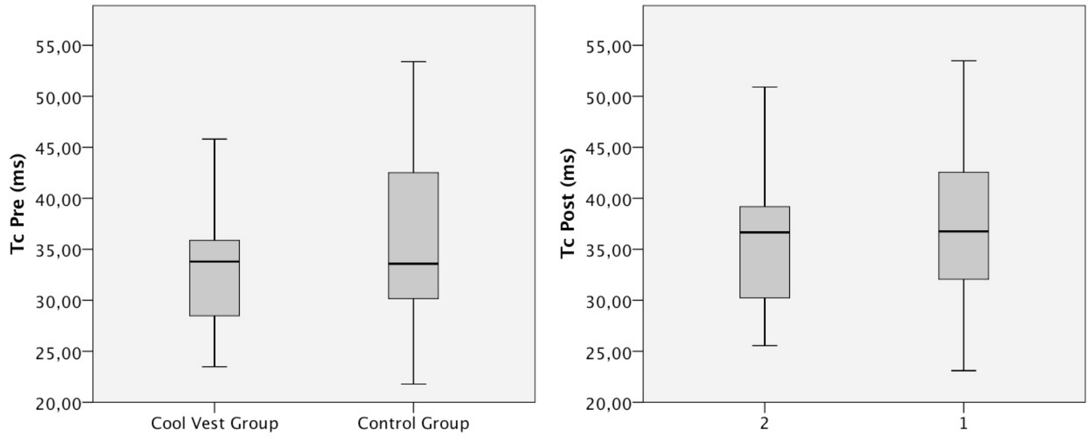
Tc indicates contraction time; Dm Maximum Deformation; Vc Contraction Velocity; Ts Sustained Time; Tr Relaxation Time; Td Delay Time; Vd Velocity of Initial Contraction deformation.

* Statistically Significant. $p<0.05$

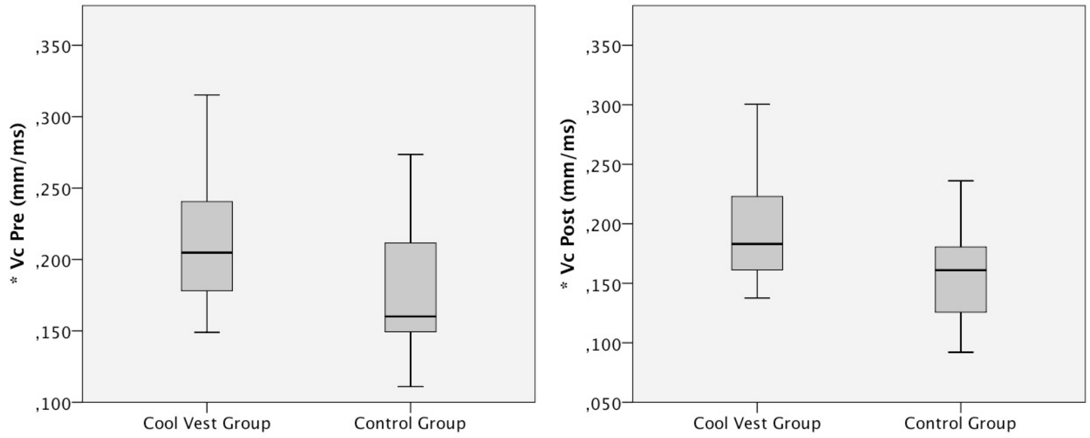
Muscle Displacement

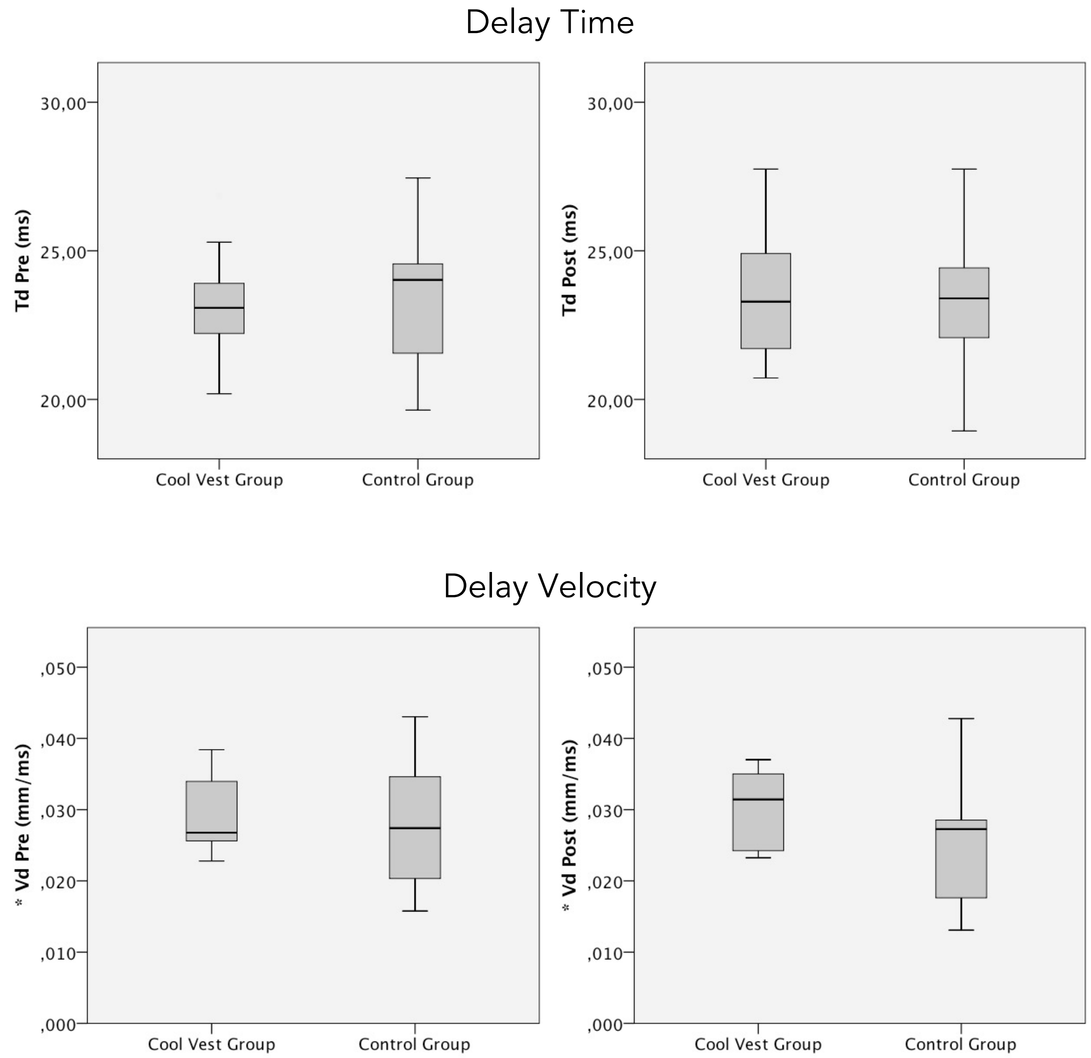


Contraction Time



Contraction Velocity





Delay Time

Delay Velocity

Figure 24. Results of *Muscle Displacement (Dm), Contraction Time (Tc), *Contraction Velocity (Vc), Delay Time (Td) and Delay Velocity (Vd). *$p<0.05$

5.5 Discussion

The main objective of this study is to analyse the response of contractile response in the femoris bicep muscle after the cool vest jacket application. The main findings are as follows: compared with control conditions, Cool Vest Jacket Vc increases maximal muscle deformation and contraction velocity until 90% of this maximal deformation and also the first 10% of maximal muscle displacement.

Muscle force is assessed as a good indicator of the ability to perform (Dahmane et al., 2001). Reductions in post exercise maximal voluntary contraction results from a combination of reduced neural activation of skeletal muscle system (Nybo & Nielsen, 2001) and impairment of peripheral contractile ability (Hargreaves, 2004). Dm is considered a measure of stomach muscle radial stiffness. Increasing this variable indicates a smaller stomach muscle radial stiffness, while a reduction of this value shows a greater stomach muscle radial stiffness (de Paula Simola et al., 2015; Garcia-Manso et al., 2012; Gleeson et al., 1998). This value combined with the velocity of muscle contraction is associated with a muscular fatigue (Dahmane et al., 2001; Rusu et al., 2013).

Post-exercise cooling techniques enhance the recovery of maximal voluntary contraction due to the faster return of central activation attributed to the reduction of Core Temperature according to previous research (Peiffer et al., 2010; Vaile et al., 2008; Vaile et al., 2011). Rapid cooling of the skin is able to activate mechanoreceptors stimulating nociceptive and metabosensitive muscle afferents (O'Connor et al., 1999) that could lead to an activation of the neural drive of the muscles (Prasartwuth et al., 2005) thus, some detrimental peripheral alterations such as the impairment of neuromuscular transmission, the reduction of sarcolemmal excitability and perturbation of muscle action potential propagation (Wilcock et al., 2006) might show reduction in its detrimental responses on muscle contraction.

This reduction could be explained because of the nervous system due to the beneficial effects of cold during recovery, as vasoconstriction may limit vessels' permeability and thus inflammatory processes, reducing muscle pain may change its strategy of muscle activation (Bailey et al., 2007; Hodges et al., 2011), to rapidly recover baseline strength levels after cold application (Hausswirth et al., 2011). Therefore, this may support the idea of the cool vest as a neuromuscular recovery method; maintaining individual force and velocity reacting ground forces in spite of the match-induced fatigue.

Some studies have reported a leg stiffness sensation after cold water exposure, probably because of the lower muscle temperature after using this recovery method right on the muscle for a long time (Booth et al., 2001; Garcia-Manso et al., 2011). This stiffness and the effects of a cooling method on muscle contraction might have an origin in an alteration in the regulation of intracellular Ca2+ in the reduced Dm and Vc of control group after the fatigue protocol, as sarcoplasmatic reticulum Ca2+ is reduced after fatigue-inducer exercise, leading to changes in the viscoelastic properties of the muscle (Garcia-Manso et al., 2011; Makinen et al., 2005), which increases with lower temperatures.

The cool vest was chosen as a cooling recovery method instead of other techniques like cold water immersion, because of its easy application and the capacity to cover a large skin surface, maximizing conductive cooling to avoid negatively affecting muscle contraction and aiming to enhance the ability of the body to dissipate heat through convective cooling (Tam et al., 1978). Also, a greater skin area covered increases the input received by the afferent system to the thermoregulatory centre, producing a faster reaction of the autonomic and the parasympathetic nervous system, and the response of the vasomotor control (Boot et al., 2006; Griggs, Leicht, et al., 2015).

To induce a significant increase in nerve conduction velocity, 20 minute cooling times have been used (Grey et al., 2001; Schieppati et al., 1997). Although an increased cooling duration in the present study may have resulted in greater decreases in Tbody, in our study, we used 15 minutes cooling, the same time as the half time of a soccer match. We found that, between 5 and 10 minutes once the cool vest is applied, Tskin and Tbody stop increasing and begin reducing their temperature. A greater benefit may occur in game situations with more frequent and longer rest intervals, which could allow for significant decreases in body temperature (Duffield, 2008). Tensiomyography showed this improvement in nerve conduction velocity. Vc value showed that the decrease of the velocity to achieve maximum muscle displacement, when achieving more displacement is inversely proportional to muscle fatigue (Krizaj et al., 2008), this suggests a correlation between a slower Tc and a greater Dc, having less reduction in Vc as a result, which is interesting to achieve a good response of the dynamic knee defence mechanisms.

On the other hand, values about the muscle activation time after the electrical stimuli, showed the capacity of the muscle afferents to respond to an external stimulus almost at the same level as before. These ergogenic benefits of the cool vest jacket may affect muscle recruitment due to the improvement in voluntary activation and Central Nervous System drive (Pointon et al., 2012), our findings are related to those demonstrating recovery using cooling techniques on the recovery of voluntary forces. Some researchers suggest that the increment of cerebral oxygen availability due to the reduced thermal load and blood flow, eases the capacity of maintaining neuronal activity (Billaut et al., 2010; Rupp et al., 2008).

The biochemical mechanism of muscle contraction may suffer a big alteration after the direct application of cold. The analgesic effect of cryotherapy methods might also increase the activation threshold of nociceptors. Modifying the nerve conduction in the structure of the axonal membrane (Luzzati et al., 1999) and the conductance of the sodium and potassium channels (Dioszeghy et al., 1992). Furthermore, a reduction of calcium release from the sarcoplasmatic reticulum diminish the availability in adenosine triphosphate (Garcia-Manso et al., 2011), resulting in an increment of the nerve action potential and a reduction of the rate of impulse transmission (Herrera et al., 2010).

As seen in some other researches with cool vests (Brade et al., 2010; Lopez et al., 2008), some results were not significant between groups, but the outcome was favourable to cool vest group for all tests. This assumption confirms the same results of some other studies investigating intermittent-sprint performance (Drust et al., 2000; Duffield et al., 2003), and finding non-significant benefits on their results.

5.6 Conclusion

The effects of the cool vest jacket as a recovery method after a fatigue-induced protocol did significantly maintain or improve the baseline values of the contractile properties of the muscle. Therefore, we cannot say that the ergogenic effects of the ice are beneficial to sports performance, but what our results suggest is that the cold vest jacket is not detrimental to muscle nerve conduction because is not directly applied and has a positive tendency to increase the neuromuscular function and response when fatigued in lab conditions.

Furthermore, applying the cool vest for longer or until as close as possible to the exercise should be more beneficial for endurance and sub-maximal exercise, such as those performed in team sports. Further research is needed about the length of the cold application, and a more accurate sports protocol involving specific actions, with sports apparel and decision-making conditions.

Chapter 6

Effects of Halftime Recovery with a Cool Vest Jacket on Kinematics of a Drop Vertical Jump

6.1 Introduction

Anterior cruciate ligament (ACL) injuries are a traumatic sports-related injury that often occur in the absence of contact with another player. Numerous studies have highlighted the preventable nature of ACL injuries via a reduced rate of injury following injury prevention programmes (Lewis et al., 2016; Meyer et al., 2017; Sugimoto et al., 2016). Injuries to the ACL occur more frequently in sports that require frequent landing and cutting movements (Alentorn-Geli et al., 2014a). Primary prevention of injury is an effective means for avoiding future disabilities (Alentorn-Geli et al., 2014b).

ACL injury risk increases when the ligament isn’t capable to cope with the load of the forces applied (Lloyd, 2001). These injuries often happen in sports during landing activities, during unilateral foot contact, requiring the athlete to bear all bodyweight through a single limb, either in noncontact situations or change-of-direction movements (Boden et al., 2000; Cochrane et al., 2007), more specifically in the deceleration phase immediately after initial ground contact (Griffin et al., 2006; Koga et al., 2010) with a lateral and extended trunk position, in conjunction with a forceful valgus collapse and tibial rotation with the knee in a relatively extended position (Hewett et al., 2009; Olsen et al., 2004; Sheehan et al., 2012). There have been several studies supporting these conclusions of actions that increase ACL loads, such as knee valgus and internal rotation moments (Oh et al., 2012; Shin et al., 2011; Withrow et al., 2006), reduced knee flexion (Mizuno et al., 2009; K. A. Taylor et al., 2011), and large anterior tibial shear forces (DeMorat et al., 2004; Yu et al., 2006). Dynamic valgus movements have been observed to come from activities that induce peak knee loads during athletic tasks (Kipp et al., 2011; McLean, Huang, et al., 2005) of knee abduction, hip adduction and internal rotation (Donnelly et al., 2012; Hewett et al., 2005; Powers, 2010).

A screening method must be appropriate and relevant to its selected purpose, and it is imperative that the constructs or criteria examined align with the constructs of interest. Considering this, screening methods that identify athletes who employ movement strategies that result in high knee loads across multiple planes are likely to be the most effective in classifying ACL injury risk. Laboratory-based measures [e.g. three-dimensional (3D) motion analysis, force plates] can accurately estimate segment motions and joint kinetics during sporting movements, providing an option to evaluate movement strategies or techniques that may predispose an athlete to ACL injury; however, although these techniques are highly validated, this approach requires extensive laboratory-based equipment and training to complete (Damsted et al., 2015; Gwynne et al., 2014; Norris et al., 2011).

Previous authors have examined lower extremity imbalances via frontal plane knee motion using 2D cam methods to analyze knee valgus collapse during dynamic tasks (Ekegren et al., 2009; McLean, Walker, et al., 2005; Munro et al., 2012; Nilstad et al., 2015). This is likely due to the notion that valgus loading has been shown to significantly increase ACL loads (Oh et al., 2012; Shin et al., 2011; Withrow et al., 2006), is often associated with ACL injury occurrences (Hewett et al., 2009; Olsen et al., 2004), and has been identified as a significant predictor of ACL injuries (Hewett et al., 2005).

Muscle fatigue plays an crucial role since a high number of ACL injuries in professional football players happen between the 75th and 90th minute of the game (Hawkins et al., 1998). Studies have demonstrated that muscle fatigue is associated with a deterioration of proprioceptive function (Jerosch et al., 1996). Also peripheral fatigue reduces stretch reflex activity (Avela et al., 1998; Nicol et al., 1996) causing negative effects on knee kinematics having a larger knee moment (Wikstrom et al., 2004) and reducing knee stability (Skinner, Wyatt, Hodgdon, et al., 1986; Wojtys et al., 1996).

Different post exercise recovery methods are used to ensure that players recover between sessions or games (D. Bishop, 2008; Thomas et al., 2017). The most used were cold water immersion and contrast water therapy (De Nardi et al., 2011) , active recovery (Andersson et al., 2008), massage (Barnett, 2006), stretching (Reilly et al., 2005), compression garments (Valle et al., 2013) and electrical stimulation (Thomas et al., 2017).

Some recovery methods often used in sports to enhance the effects of body cooling are cryotherapy and cold water immersion. The mechanism for recovery is attributed to its vasoconstrictive effect, reducing the inflammation reaction through a decrease of the cell metabolism (White et al., 2013), blood flow, temperature and intramuscular nerve conduction velocity (Bleakley et al., 2013). Also, cooling reduces the rate of perceived exertion (RPE) affecting general comfort and improving overall subjective ratings (Barnett, 2006) which might be beneficial to fasten recovery during half time of a game.

The objective of this study was to investigate how much a cool vest jacket influences in knee stability during the 15-minute break of a soccer match. For this purpose, we designed a 45-minute fatigue soccer protocol on a treadmill and after that the participants performed a drop vertical jump. The hypothesis of the study was that the experimental group has less reduction of knee stability due to the effects of the cool vest as a recovery method.

6.2 Methodology

Participants

A total of 30 healthy males, recreational soccer players, were assessed. Their characteristics were as follows (mean ± SD): age, 22.27 ± 2.78 years; body weight mass, 71.67 ± 7.27 kg; body height 176.12 ± 7.44 cm; body mass index 23.08 ± 3.13; peak oxygen consumption (VO2peak) 58.18 ± 2.7 mL/Kg/min. The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. This study was designed according to the standards of Bioethics committee of the University of Barcelona and according to the principles of the Declaration of Helsinki of 1975, reviewed on 2008. Participants referred not having any injury in the 6 months prior to the study. For a period of 48 h before each trial, they were instructed to refrain from strenuous exercise. Furthermore, the participants were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before each trial. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials. The subjects received no economic reward for their participation in the study.

Study Design

The repeated measures study was designed to compare the frontal projection angle (FPPA) of the knee valgus during a drop vertical jump (DVJ). Prior to data collection, the weight and height of all the participants was measured. Then participants completed a 15-minute warm-up consisting off self-paced running on a treadmill, and always finalizing with maximal counter movement jumps (CMJ). Then three DVJ were performed by the participants with a resting time of, at least, 60 seconds between attempts (Bogdanis et al., 1998). Starting stood with their feet shoulder width apart on a 40cm high box, and a stick behind their head to normalize arm position, the participants were instructed to drop off the box, reach a 90-degree angle and perform a maximal jump after landing. While subjects performed the DVJ, they were recorded with a high-speed video camera (Casio Exilim Pro Ex-F1®) was placed on a tripod 3 meters directly in front of the subjects at a speed of 400 Hz. This method has recently been validated to the calculation of kinematic variables with high speed video registrations (Balsalobre-Fernandez et al., 2014). Jump height and contact time was also recorded using the validated (de Blas et al., 2012) contact platform, Chronojump Boscosystem (Spain)

After 3 attempts, they undertook a running protocol simulating a part of a soccer match on a treadmill consisting on 5 bouts of 9 minutes of different speeds based on data derived from a study that analyzed Spanish soccer players during first division league games (Di Salvo et al., 2007). The speeds were 6.5, 12.5, 16.5, 21 and 23 km/h representing 63%, 14%, 15%, 5% and 3% of the protocol respectively. Every bout was organized in an acyclical order trying to approach the variability of a soccer match play. Participants then rested in a seated position for the 15 minutes simulated half time, recovery involved the use of the cooling vest or not. Afterwards, the participants performed three more DVJ emulating the same conditions as before.

Analysis of 2D Data

To determine FPPA from 2-D video capture, markers were placed bilaterally with double-sided tape over the following anatomic landmarks: iliac crest, midpoint of the femoral condyles to approximate the center of the knee joint, the midpoint of the ankle malleoli for the center of the ankle joint. All markers were placed by the same evaluator. Digital videos were imported and assessed using the motion-analysis software Kinovea (version 0.8.15), that has already been validated for jumps height, time contact and knee angle assessing (Balsalobre-Fernandez et al., 2014; Norris et al., 2011).

We analyzed the deceleration phase of the DVJ as a landing cycle, initial foot contact (IC) to peak knee flexion (MAX), because this is the most common used during injury prevention assessment and clinical evaluations (Alentorn-Geli et al., 2014a; Fox et al., 2016). From a frontal view, when the knee marker was medial towards a line from the angle marker to the thigh marker, the FPPA was negative. FPPA was positive if the knee marker was lateral to a line from the ankle marker to the thigh marker. Knee valgus was marked through negative FPPA values, meanwhile positive values denoted a dynamic knee varus (Ford et al., 2003; Munro et al., 2012; Willson et al., 2008).

Knee angle at IC and valgus maximum during peak knee flexion were recorded. Bilateral valgus knee motion was calculated from the frontal plane distance between the knee markers during the DVJ, as stated by other authors who already conducted researches assessing knee distance during a DVJ (Ford et al., 2003; Sigward et al., 2011)

Mean FPPA value from three trials was used for analysis as this was found to be the minimum number of measurements needed to be able to obtain a consistent average and could also be used to assess for within-session reliability (Munro et al., 2012; van der Leeden et al., 2004). The reliability of 2-dimensional video assessment, error measurement and validity has previously been established compared to 3d measures (Munro et al., 2012).

Cooling Garments

The Ice jacket used during the 15-minute recovery time is made of neoprene and has twelve ice-packs sorted around the trunk, eight on the chest and stomach and four over the back. The ice packs were stored for a minimum of 12 hours in a conventional freezer. The cool vest was worn directly on top of the participants' clothing as they rested in a seated position. Participants wore the same clothing during the trial (running and soccer shoes, sports socks and a soccer shirt).

Figure 25. Initial position before the DVJ on a 30cm box and arm standardized position

6.3 Statistical Analysis

Descriptive statistics (mean and standard deviation [SD]) were computed and presented for each dependent variable. Intraclass correlation coefficient (ICC) was used to estimate the intrarater reliability. A two-way ANOVA was used to determine significant differences for all of the variables of interest. Paired t-tests were used to examine simple effects in the case of a significant interaction. The p-value was set at $p \leq 0.05$. All statistical analyses were carried out using SPSS statistical software package version 23.0 (SPSS Inc., Chicago, IL).

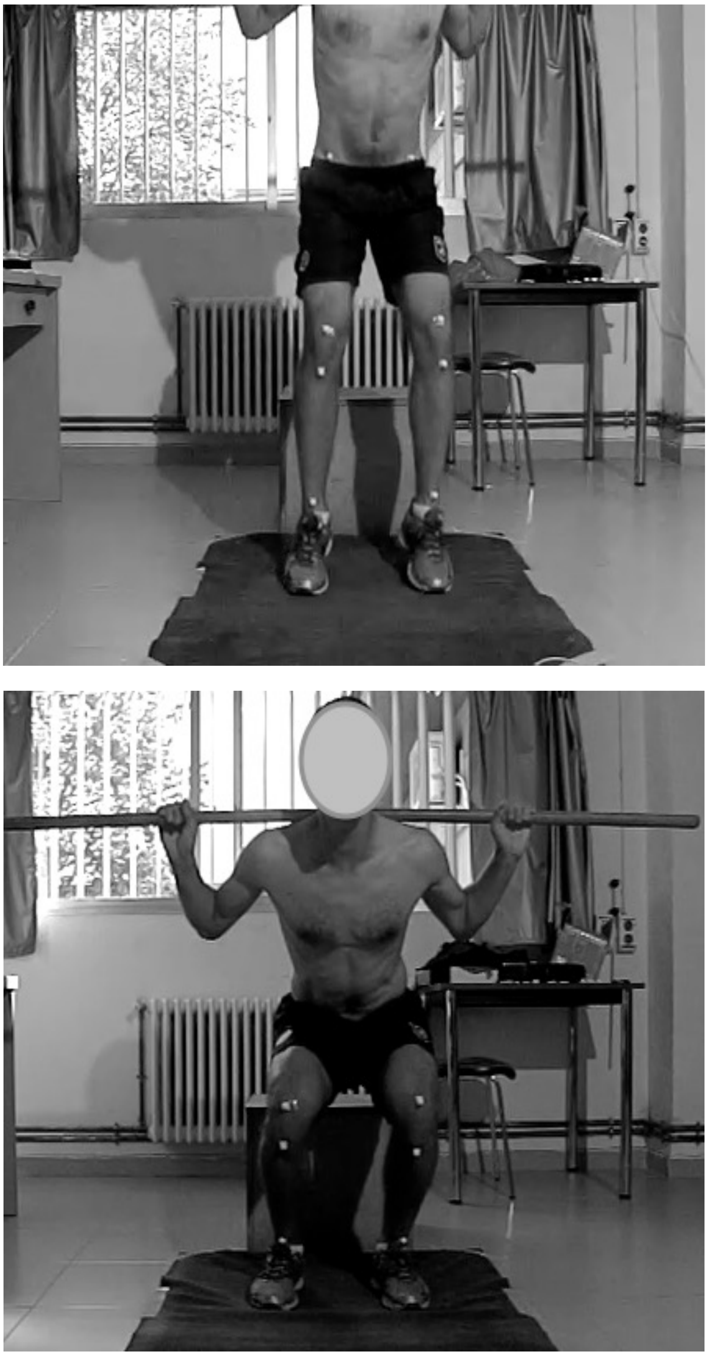


Figure 26. Initial contact moment and Maximum eccentric position during the DVJ

LANDING ANALYSIS WITH KINOVEA

Figure 27. Tracing two straight lines. One from the ankle crossing the knee, and the other from the knee to the iliac crest.

Figure 28. FPPA degrees

6.4 Results

The average measures of ICC between the two different moments in the videos were examined, measuring the different phases of a DVJ were (0.789 and 0.794) and the p-value was 0.0001 for both examiners.

Analyses are divided in two groups, the group that wore the cool vest jacket during 15 minutes after the soccer running protocol and the group that didn't. Mean values and standard deviation for dominant knee and non-dominant knee groups are shown in Table 1. Also, in table 3 are shown the results in time contact and height during the DVJ.

Table 7. Means and standard deviations of FPPA on Dominant and Non-Dominant leg (º)

		Cool Vest		Control Group	
		Dom	Non-Dom.	Dom	Non-Dom.
PRE	IC	4.85±5.52	9.87±5.50	4.53±7.02	7.60±7.10
	MAX	19.17±15.22	12.36±23.99	20.33±23.35	16.88±25.15
	DIF	14.32±15.17	2.49±21.02	15.80±21.55	9.29±21.71
POST	IC	4.08±5.17	10.20±4.91	3.08±6.52	8.13±7.19
	MAX	24.42±22.44	18.73±26.75*	22.00±27.78	19.24±22.74
	DIF	20.33±19.50	8.53±24.91	18.91±23.35	11.11±19.58
DIF PRE-POST		6.01±11.52*	6.04±10.69*	3.11±13.98	1.82±14.21
	p	0.048	0.046	0.404	0.627

* Significant differences ($p<0.05$)

PRE is the baseline test before the soccer protocol and POST is afterwards.

IC is initial contact, MAX is the peak knee flexion, and DIF is the difference between them.

FPPA

After the fatigue protocol, the results obtained showed that values tend to reflect a varus alignment in both knees, displacing away from the midline of the body. The two-way ANOVA didn't reveal any significant interaction in dominant knee (F=0.384 p=0.541) or non-dominant knee (F=0.845 p=0.366) during the DVJ. Nevertheless, the follow-up paired t-test of FPPA within conditions indicated that those who wore the cool vest tended to move toward a varus alignment during the DVJ (6.01±11.52° p=0.048 and 6.04±10.69° p=0.046, dominant and non-dominant knee respectively) while also showing a significant difference before and after the fatigue protocol at the peak knee flexion on non-dominant knee (12.36±23.99 and 18.73±26.75 p=0.030 before and after the soccer fatigue protocol respectively).

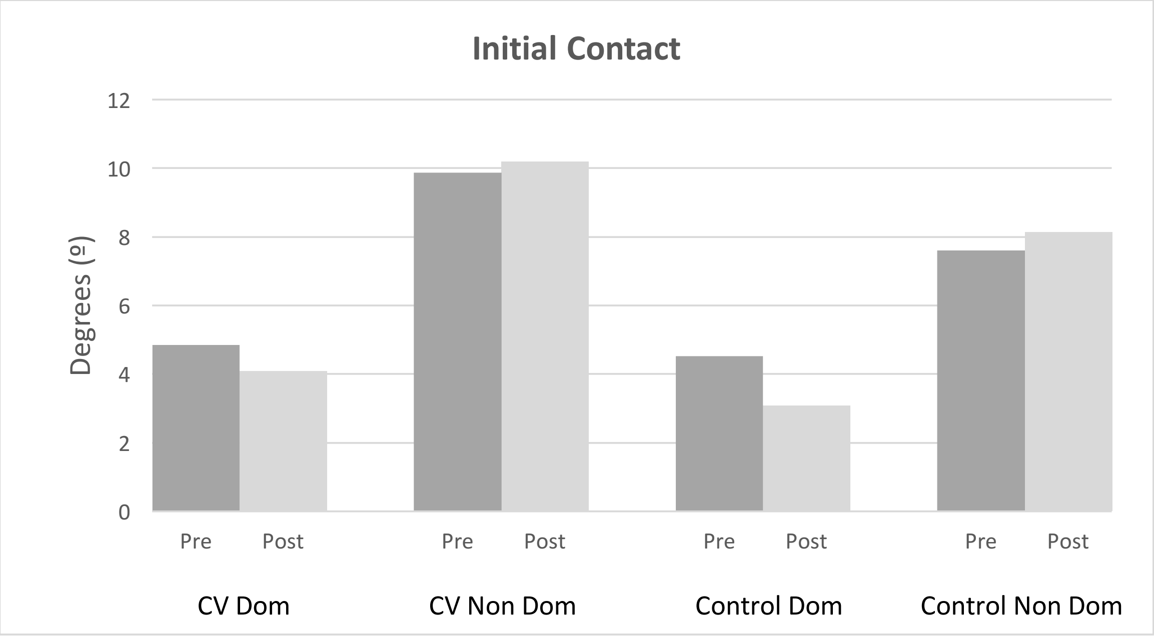


Figure 29. Point of Initial contact during the DVJ with dominant and non- dominant leg

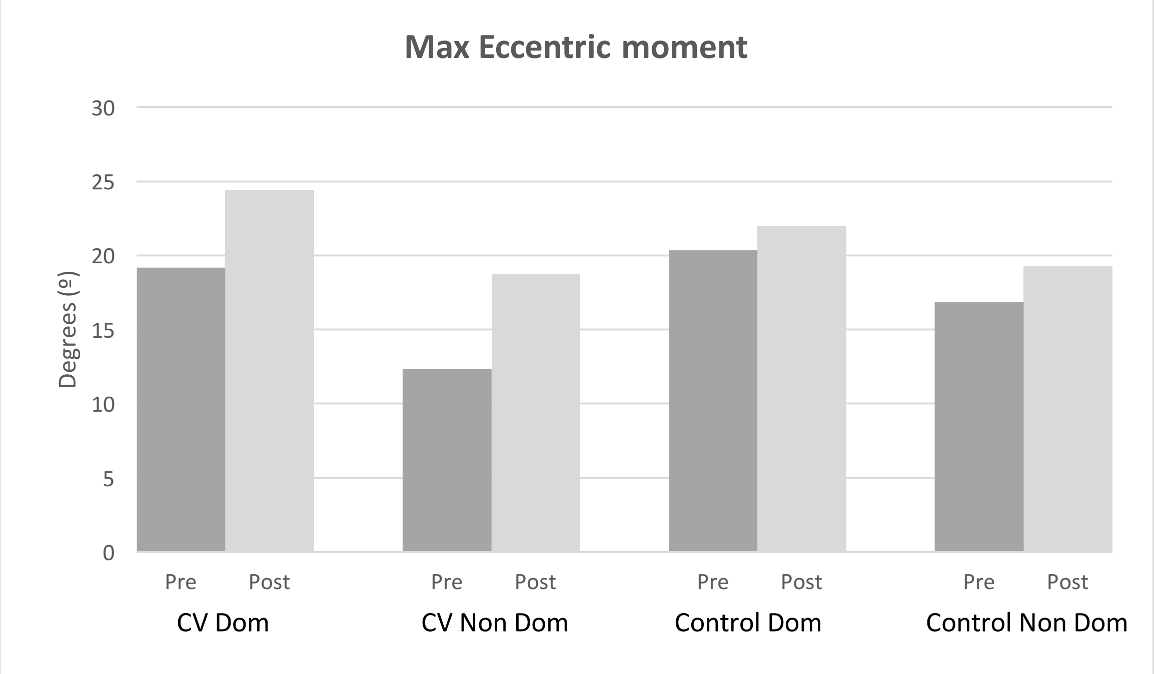


Figure 30. Maximum eccentric point during the DVJ with dominant and non- dominant leg

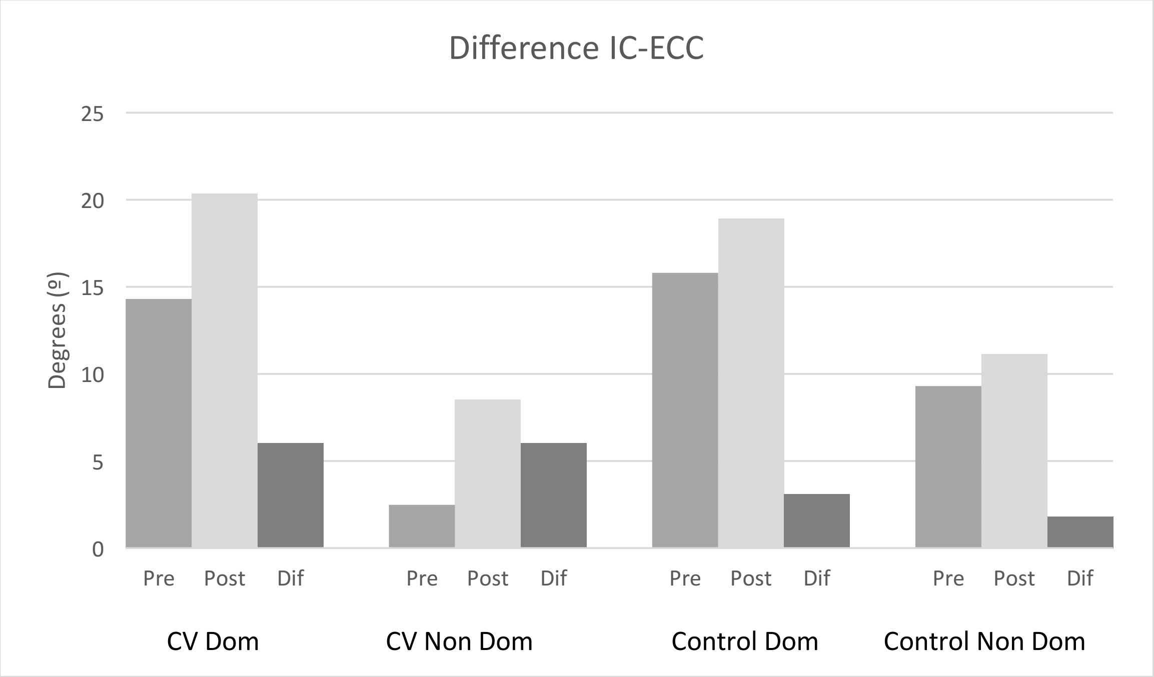


Figure 31. Differences between Point of Initial Contact and the Maximum Eccentric Point during the DVJ.

Table 8 . Means and standard deviations of knee separation

		Cool Vest			Control Group		
		Pre	Post	p	Pre	Post	p
Knee Distance (cm)	IC	37.28±4.81	38.43±5.45	0.293	38.58±6.99	39.45±6.65	0.560
	MAX	37.91±9.82	42.02±13.87	0.014*	40.34±14.16	44.26±16.28	0.221
	DIF	-0.63±7.95	-3.58±10.79	0.014*	-1.76±11.13	-4.80±11.28	0.222

* Significant differences (p<0.05)

PRE is the baseline test before the soccer protocol and POST is afterwards.

IC is initial contact, MAX is the peak knee flexion, and DIF is the difference between them.

Knee separation

The knee separation distance didn't show any statistically significant difference on time x condition assessing the difference between the point of initial ground contact and the peak knee flexion between conditions (F=0.001 p=0.973). But significant results were found assessing group paired t-test during the peak knee flexion moment (t=2.804 p=0.014) and the difference with the initial ground contact (t=2.809 p=0.014), landing with less knee separation than the control group.

Table 9. Means and standard deviations of ankle separation during peak knee flexion

	PRE	POST	T	p	ANOVA	F	p
Control Group	32.44±6.79	35.17±7.67	2.325	0.038*	Time	5.773	0.024*
					Group	1.380	0.251
Cool Vest Group	30.12±6.16	31.51±7.64	1.128	0.278	Interaction	0.620	0.438

* Significant differences (p<0.05)

PRE is the baseline test before the soccer protocol and POST is afterwards.

Ankle separation distance

Ankle separation distance was also measured to assess compensation to fatigue during the eccentric phase. The results obtained showed that the fatigue protocol had a significant effect on ankle separation in both groups increasing the distance between them (F=5.773 p=0.024). Although the interaction group x time didn't reflect any statistical difference (F=0.620 p=0.438), the paired t-test reflect significant differences on ankle separation only in the control group (32.44±6.79 to 35.17±7.67, t=2.325 p=0.038) meanwhile the cool vest group remained statistically unmodified (t=1.128 p=0.278).

Drop Vertical Jump

DVJ results, shown in table 2, compared with initial values didn't show any significant difference in the interaction between groups (F=0.017 p=0.896). After the t-tests, control group significantly declined height jump after the intermittent protocol (33.60±5.20 to 32.31±5.25 cm, t=1.795 p=0.048) meanwhile cool vest group maintained their performance (35.01±5.16 to 33.87±5.01 cm, t=1.330 p=0.205). Ground Ct didn't show statistical differences in the interaction between groups (F=0.026 p=0.874), although there was a different tendency than DVJ. After the statistical procedure, both groups maintained their ground time contact compared to baseline conditions, control (541.56±80.65 to 546.09±68.11 ms, t=0.023 p=0.982) and experimental group (522.76±105.15 to 519.87±107.39 ms, t=0.211 p=0.836). Nevertheless, control condition maintains their initial time ground contact and decreased height jump, meanwhile cool vest group didn't modify their performance in any of these two variables.

Table 10 . Means and standard deviations of the variables Ct and DVJ before and after the intermittent protocol of control group and experimental (using the cool vest jacket) group.

Variable	Group	PRE	POST	T	p	F	p
DVJ (cm)	Control	33.60±5.20	32.13±5.05	1.795	0.048*	0.091	0.765
	Cool Vest	35.01±5.16	33.87±5.01	1.330	0.205		
Ct (ms)	Control	542.10±80.65	546.43±69.13	0.023	0.982	0.026	0.874
	Cool Vest	522.76±105.15	519.87±107.39	0.211	0.836		

Values are presented as mean ± SD

Ct indicates Contact Time and DVJ Drop Vertical Jump.

6.5 Discussion

The purpose of this study was to assess the differences of the dynamic knee alignment (FPPA) via 2D video during a DVJ and performance with the height of the jump and the time contact after DVJ, before and after a running fatigue protocol in a treadmill and the application of a cool vest jacket during the following 15 minutes after the running protocol. We admit that a 2D FPPA video analysis can only describe hip, knee and ankle positions in a frontal plane although ACL injuries may happen during change of direction, and cutting movements being easier to identify combining different planes at the same time or using 3D video (McLean, Walker, et al., 2005). Although 3d methods are more precise than 2D screening methods, both have been proven to be reliable predicting knee angles (Mizner et al., 2012). Nevertheless, coaches need tools that are easy to handle and use, so they can extract information in the moment the action is happening, been able to assess the movement and give appropriate feedback without having to rely on expensive methods and machinery (McLean, Walker, et al., 2005; Sorenson et al., 2015). The hypothesis was that there would be differences in knee varus and knee separation during a DVJ between the group that used the cool vest and the group that didn't after the fatigue protocol.

During a fatigue state, all the supporting muscles of the knee joint might reduce their capacity to preserve the knee from unexpected movements (Norcross et al., 2013; Rozzi et al., 1999). Depending on the situation of the center of gravity of the upper body during landing, there might be a direct influence to the trunk affecting the lower extremity final position, also the abduction or adduction position of the trunk and hip or pronation and supination of foot and ankle are relevant during the same maneuver (Noyes et al., 2005). When neuromuscular control is impaired an "altered stiffness during landing has been linked to a decrease in a stored elastic energy and possibly a change in the sensitivity and activation of stretch reflex" (Smith et al., 2009) increasing the risk of knee injury during landing activities (Horita et al., 1996; Norcross et al., 2013) due to the production of either varus or valgus moment which must be balanced by lower limb musculature (Hewett et al., 2005). An increased knee valgus reveals the impossibility of the knee muscles to control torque during sports manoeuvres, suggesting a ligament dominance which often produces excessive forces in knee valgus motion (Ford et al., 2003) increasing lower extremity overuse and traumatic injury risk (Hewett et al., 2005; Powers, 2010).

Some of the recovery methods used during a halftime of a game, don’t last more than the 15 minutes break time, thus the method has to be easy to use and have a fast result on athlete’s body (Nedelec et al., 2012). Performing an active recovery is one of the most common methods used. The objective is to re-warm up with exercises at low intensities, aiming to remove lactate from blood more quickly, and to progressively reduce body temperature and blood flow and reducing the arousal level of the central nervous system (Lau et al., 2001; Spierer et al., 2004). Rehydration is another method, aiming to restore the level of fluids lost during the game (~2% of body mass), including electrolytes and sodium during the intake to facilitate water absorption through the intestinal wall (Kovacs et al., 2002; Shirreffs et al., 2000). Cryotherapy, by means of cold-water immersion, ice vests, or ice massage is another common method, aiming to reduce body temperature to enhance a rapid recovery. Although cold-water immersion would be an uncomfortable method, and might also reduce muscular temperature resulting in an impairment of muscle contractile capacities (Chan et al., 2017; Ihsan et al., 2016; Roberts et al., 2014).

Our results show that those who wore the cool vest tend to modify their lower limb position compared to baseline conditions, increasing the angle the knees form during a DVJ, leading to a varus alignment (6.01±11.52° $p=0.048$ and 6.04±10.69° $p=0.046$), dominant and non-dominant knee respectively. This situation leads us to think that cooling might have a beneficial effect on fatigue and neuromuscular control on knee supporting muscles.

The use of a cool vest jacket as a recovery method is supported by the fact of the large skin surface covered by the vest, maximizing conductive cooling to enhance the cold afferent receptors and trigger a fast response of the central and parasympathetic nervous system evaporating the heat from the body (Brock et al., 2016; Griggs, Price, et al., 2015; Trbovich et al., 2014). Cooling the spinal cord plays a functional role in this process, having a large amount of temperature sensory nerves compared to other parts of the body, affecting the subsequent core response (Griggs, Price, et al., 2015). Thermal stimuli could be increased by cooling the spinal cord enhancing "action potential-evoked neurotransmitter release at the first synapse in the cold afferent pathway" (Brock et al., 2016).

It is possible that using a cool vest might affect muscle blood flow by triggering physiological effects to reduce pain perception and facilitating recovery (Eijsvogels et al., 2014; Priego Quesada et al., 2015; Tyler et al., 2015). Cooling the upper body produces a reduction of skin temperature during recovery time inducing to a lower core temperature (Brade et al., 2010; DeMartini et al., 2011; Lopez et al., 2008). Decreasing core temperature seems to produce a vasodilation, affecting the sweating mechanisms, which induces a redistribution of cardiac output to supply cutaneous requirements maintaining a greater central blood volume and leading to an increment in skeletal muscle blood supply that might facilitate muscle performance (Duffield et al., 2007; Gonzalez-Alonso et al., 2003; Kruk et al., 1990).

Another possibility leans on the nerve conduction and the brain's response ability after receiving afferent information from cold receptors. Hyperthermic athletes have shown a reduction in cerebral blood flow (Brothers et al., 2009; K. Hayashi et al., 2011) and in cognitive capacity (Bandelow et al., 2010). Skin cooling might have a beneficial effect on enhancing cerebral function, attenuating the reduction in cerebral blood flow after intense exercise (Bain et al., 2015).

All these results in knee dynamic valgus and knee separation during a DVJ after using a cool vest jacket might also explain the outcomes on performance. Although no significant differences were found, as expected both groups seem to experiment a reduction in all their results after the fatigue protocol compared with baseline conditions.

After the DVJ, our control group significantly reduced jump height (p=0.048) and maintained ground contact time during the DVJ after the intermittent protocol, whereas cool vest jacket group didn't experience any modification during the performance variables of the DVJ. Curiously, the control group had to maintain their contact time to perform a lesser jump than before, which explain the necessity of a longer muscle contraction time to create the same amount of energy. In this situation, muscle fatigue leads to a major valgus collapse compared to the experimental group, which could be explained by the changes in the nervous system due to the beneficial effects of cold during recovery, as vasoconstriction may limit vessels' permeability and thus inflammatory processes. Reducing muscle pain may change its strategy of muscle activation (Bailey et al., 2007; Hodges et al., 2011), to rapidly recover baseline strength levels after cold application (Hausswirth et al., 2011).

This outcome might reflect a change in the movement pattern and, even though there's not an improvement in performance, in order to generate the same impulse force, when increasing the time contact the force applied is reduced. It has already been studied that the rate of perceived exertion is improved with cooling during halftime (Hornery et al., 2005), thus there seems to be a psychological aspect during recovery in which the participants wearing the cool vest had a better thermal sensation after wearing it. All this may support the idea of cool vest as a neuromuscular recovery method; maintaining individual force and velocity reacting ground forces in spite of the soccer-induced fatigue protocol.

6.6 Conclusion

Our results suggest that the use of a cool vest during a 15-minute break of a fatigue induced soccer protocol affects the outcome of knee position during a DVJ in normothermic conditions. Both FPPA and knee separation distance had significant results when using the cool vest that might be beneficial when protecting the ACL from unexpected events involving landing movements. Further studies are needed to confirm the effectiveness of this method during a real soccer match or a protocol that also involves a change of direction, ball actions and opposition, trying to be as close as the nature of a soccer game as possible.

Chapter 7

Physiological Effects of the Cool Vest Jacket on recovery after a Repeated Shuttle Sprint Ability test

7.1 Introduction

Soccer is an aerobic-anaerobic sport with a high number of short and intense actions that take place throughout the game (Bangsbo, 1994; Campos-Vazquez et al., 2015; Carling, 2010; Mohr et al., 2003; Rampinini et al., 2009). These high intensity actions (above 20 km/h) represent 10% of the total time while actions such as walking or running at low pace represent around 60% of the total time of a game (Bradley et al., 2010; Carling, 2010; Di Salvo et al., 2007). The ability to repeat sprints with a short recovery time is an important performance factor in team sports. The essence of the game is a succession of unpredicted actions that may create an occasion to affect the result of the game by maintaining the possession of the ball, creating more chances, scoring or prevent the opponent from develop their tactical plan (Bangsbo, 1994; Ekblom, 1986; Mohr et al., 2005; Rahnama et al., 2003).

Physiologically, fatigue puts a big strain on several neuromuscular and metabolic parameters, affecting the capacity to complete these explosive actions (Bangsbo, 1994; Bangsbo et al., 1991; Campos-Vazquez et al., 2015; Mohr et al., 2005; Robineau et al., 2012; Small et al., 2009). It is known that intermittent sprint exercise in hot conditions increases core and skin temperature producing a thermoregulatory strain, thus reducing performance. (Demartini et al., 2015; Drust et al., 2005; Priego Quesada et al., 2015; Tyler et al., 2015). Some studies have related performance of repeated sprint ability (RSA) with the distance at high intensity performed during a competition, suggesting its close relationship to soccer performance (Aziz et al., 2008; Rampinini, Bishop, et al., 2007). A close follow-up and control of this type of exercise during practice may be of high importance to the player’s performance on the field.

Several methods have been used to analyse the physiological demands of team sports during practice and games, some of the most used include heart rate (Alexandre et al., 2012; Bosquet et al., 2008) and blood lactate sample (Eniseler, 2005; Mohr et al., 2004)

Various research studying fatigue on intermittent exercise show that values of 10-15 mmol·l^{-1} of blood lactate concentrations are reached during some standardized RSA testing (Caprino et al., 2012; Castagna et al., 2008; Castagna et al., 2007; Glaister et al., 2010), this being a considerately higher amount respective to values collected during real team sports games such as soccer, basketball and rugby that normally oscillate between 3 to 10 mmol·l^{-1} (D. Bishop et al., 2011; Caprino et al., 2012; Coutts et al., 2003; Stolen et al., 2005).

Thermal stress has been studied showing that a significant increment of Core temperature (Tc) might reduce intermittent-sprint performance (DeMartini et al., 2011; Drust et al., 2005; Ross et al., 2013) and endurance (Gonzalez-Alonso, Teller, et al., 1999) compared to normothermic conditions. Fatigue and the rapid rise in body temperature leads to a decrease in skill performance probably because of the impairment of the central nervous system due to the thermal strain (Girard et al., 2011; Sunderland et al., 2015).

As a consequence, some methods to reduce thermal strain such as cryotherapy, ice slurry ingestion, cool vest, fans, cold baths, neck and palm cooling (Duffield et al., 2007; Marino, 2002) have been used to benefit recovery directly affecting an athlete’s thermoregulation system, mainly during warm-up (Arngrimsson et al., 2004; Castle et al., 2006; Quod et al., 2006), during exercise (Hasegawa et al., 2005; Lopez et al., 2008) and whole body cooling during recovery sets (Hornery et al., 2005; Yeargin, Casa, McClung, et al., 2006).

As far as we know, little is known about physiologic effects after upper body cooling during recovery of a RSA in hot conditions. Therefore, the aim of the present study was to examine the effect of a RSA protocol on blood lactate, heart rate and skin temperature during the recovery period with and without a cool vest jacket in hot conditions.

7.2 Methodology

Participants

Twelve healthy males, recreational players [age 21.9±1.7 years, height 177.4±5.4, body mass 23.28±1.9, peak oxygen consumption (VO2peak) 57.4±3.1 mL/Kg/min) participated in this study. The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. The protocol was made according the ethical principles of The World Medical Association's Declaration of Helsinki of 1986. For a period of 48 h before each trial, the participants were instructed to refrain from strenuous exercise. Furthermore, the participants were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before each trial. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials. The subjects received no economic reward for their participation in the study and had no previous injury in the 6 months prior to the study too.

Study Design

For this study, participants attended three times. The first one was used as a familiarization session, in which the whole study was explained with visual examples, and a written consent was signed. Testing was performed in warm environmental conditions (31.8±1.4° and 39±4.2% relative humidity with a wind effect of 1.2±0.4 m/s) at the same time of the day from 10 am to 12 noon to minimize effects of diurnal variations on the measured variables (Atkinson et al., 2010). There were no significant differences in temperature, relative humidity and wind between both testing days.

The participants came on two more days separated by 48 hours at the same time of the day to perform identical sessions in a randomised use of the cool vest, only one of the days they recovered wearing the cool vest. When they arrived to the facility, height, weight, baseline temperatures, heart rate and lactate were taken. They performed a self-paced warm-up involving dynamic mobility, jumps, accelerations and change of direction, after that the same measures were taken. The RSSA test was undertaken and then they rested with and without the cool vest. Measures of heart rate, blood lactate and temperature were taken at 1, 3, 5 and 10 minutes of the recovery period.

RSSA

In our study, we defined the Repeated Shuttle Sprint Ability as "the ability to repeatedly produce maximal or near maximal series of shuttle sprints with brief recovery periods". To measure RSSA, we used a test consisting of six 40-meter shuttle sprints (20-meter + 20-meter with a 180° turn) with 20 seconds of passive recovery (Buchheit, Mendez-Villanueva, et al., 2010; Impellizzeri et al., 2008). The participants started from a line behind the infrared photoelectric cells (Artek Pro ®), sprinted for 20 meters, touched a cone and run back to the starting line as fast as possible. Subjects were encouraged to decelerate as soon as possible, after crossing the cells and finishing the bout, and head back to the starting line again, set exactly 50 cm before the line covered by the first photocell (Gharbi et al., 2014). The photocell was placed at the participants' ear height to avoid an accidental activation of the photocell with their arm or trunk. The participants rested for 20 seconds and started again. After the warm-up, the participants completed a single shuttle run to have their criterion score (Impellizzeri et al., 2008), then participants rested for 5 minutes before the beginning of the test. The following data was recorded during the RSSA test: the fastest time, the average time, and the percentage decrement score calculated as follows: 100 – (mean time/best time x 100) (Buchheit, Bishop, et al., 2010; Glaister et al., 2008).

Figure 32. RSSA Starting Position

Figure 33. 180° Change of direction after touching a cone

Physiological Measures

Heart rate was measured (RCX5, Polar, Finland) as a baseline, right before the first run, and during the minute 0, 1, 3, 5, 10 and 15 of the recovery period. Blood lactate concentration was obtained from the fingertip of the left hand, with the participants in a seated position, then a baseline measure pre-intervention taken, a pre-RSA measure and then a measure at the minutes 1, 3, 5 and 10 of the recovery period. Blood lactate concentration was measured with a portable analyser (Lactate plus DP 110, Diaglobal). The finger was cleaned with alcohol and dried before and after every measure.

Tympanic temperature (Tt) was measured by the Riester Ri-Thermo® N thermometer (Jungingen, Germany). The thermometer measured the infrared radiation generated by the eardrum and the surrounding tissue. The technical error of measurements amounted to 0.2 for temperatures in the range of 32.0° to 42.2°. Skin temperature (Ts) was measured using the Iberia PCE-891 infrared thermometer (Albacete, Spain), which has a resolution of 0.1° (measuring range -50° to +1600°). The precision of measurement in the temperature range of our test was ±1,5 % of ±2 °C range (manufacturer's information). Measurements were performed in right scapula, left arm in upper location, right anterior thigh and left calf according to ISO 9886 (2004). To ensure measurements were done in the same place, locations were marked with a marker. Skin temperatures were measured with a 5-point method at skin surface of the right scapula, left chest, left arm in upper location, right anterior thigh and left calf. The mean skin temperature was calculated using the equation: 0.3 (Chest + Arm) + 0.2 (Thigh + Calf) (Ramanathan, 1964).

Figure 34. Resting with the cool vest jacket

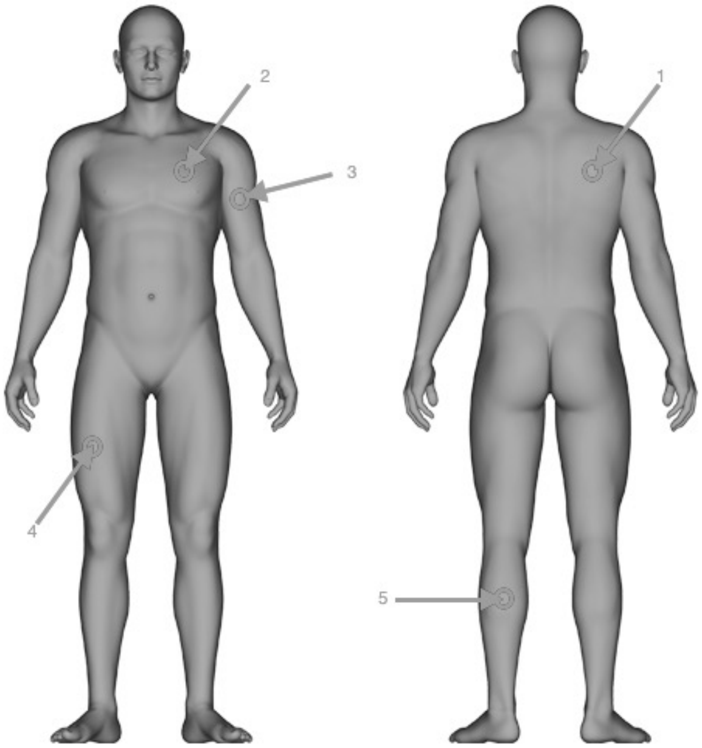


Figure 35. Skin temperature measured from right scapula (1), left chest (2), left arm in upper location (3), right anterior thigh (4) and left calf (5).

Cooling Garments

Cool Vest is made of neoprene and has twelve pockets for ice-packs, eight on the chest and stomach and four over the back. The ice packs were stored for a minimum of 6 hours in a conventional freezer. The cool vest was worn directly on top of the participants' clothing as they rested in a seated position. Participants wore the same clothing during the trial (running shoes, sports socks and a T-shirt).

7.3 Statistical Analysis

Results are expressed as mean values ± SD. Because normal distribution of the data was verified by means of Levene's and Shapiro-Wilk normality test, parametric statistics were used. Intraclass correlation coefficients were calculated to determine the test-retest reliability of the RSSA, the following criteria were adopted for interpreting the magnitude of correlation (r (90 % CL)) between test measures: ICC values were interpreted according to criteria outlined by Coppieters et al. (2002) poor < .40, fair .40 to .70, good .70 to .90, and excellent > .90.

Independent t-tests were performed to identify significant differences between cool vest and control session after the recovery period. Statistical significance was set at $p<0.05$ for all analyses. All data was analyzed using SPSS (Version 23.0.0, Chicago, IL, USA).

7.4 Results

RSSA

The mean results of both measures for both days the participants undertake the RSSA test and the Intraclass Coefficient Correlation (ICC), that has been used to analyze the reliability of the tests are summarized in Table 11. The average RSSA time was 7.65±0.24 seconds the first day they undertook the test and 7.61±0.25 seconds the second (0.447; 0.961, 95% CI and a 0.85 ICC), meanwhile the decrement percentage was a 4.92±2.76% and a 4.84±2.55% (-0.580; 0.900, 95% CI and a 0.62 ICC) the first and second day, respectively. These results are expressed independently whether they were or were not wearing the cool vest jacket.

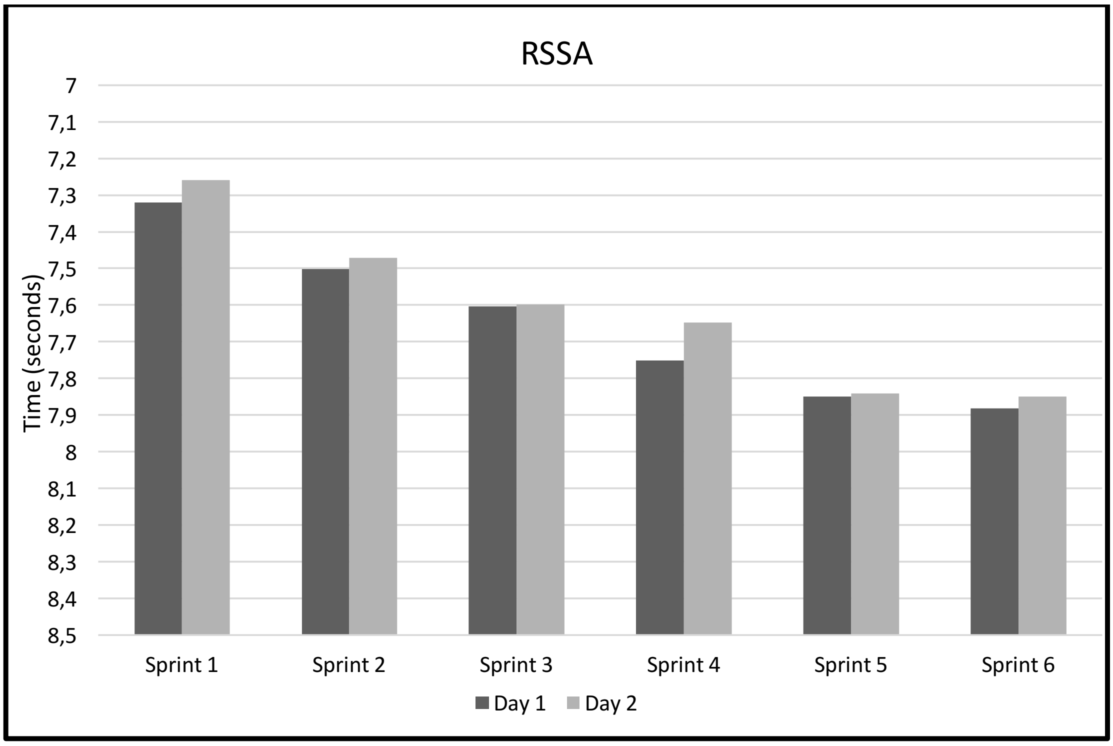


Figure 36. RSSA performance both testing days.

Table 11. RSSA Results

	Day 1	Day 2	95% CI	ICC	t(10)	Sig. (2-tailed)
Sprint 1	7.321±0.46	7.260±0.36	0.633 to 0.972	0.90	0.789	0.449
Sprint 2	7.502±0.44	7.471±0.42	0.576 to 0.970	0.89	0.361	0.726
Sprint 3	7.603±0.37	7.599±0.41	0.497 to 0.965	0.87	0.490	0.962
Sprint 4	7.751±0.43	7.648±0.49	0.347 to 0.950	0.81	0.931	0.374
Sprint 5	7.849±0.45	7.842±0.57	-0.083 to 0.929	0.73	0.520	0.960
Sprint 6	7.881±0.55	7.849±0.63	0.166 to 0.944	0.79	0.206	0.841
Mean	7.651±0.24	7.611±0.25	0.447 to 0.961	0.85	0.409	0.691
% Dec	4.92±2.76	4.84±2.55	-0.580 to 0.900	0.62	0.092	0.929

Date are mean ± SD. Sprints and Mean are expressed in seconds.

Mean: mean sprint time of the six sprints

%Dec: percent sprint decrement for the six sprints.

A CVJ was randomly used on one of the two testing days. Skin temperatures (Table 12) were measured as a baseline and pre RSSA testing showing non-significant differences (p=0.560 and p=0.628, baseline and preRSSA respectively). Another measure was taken at the end of the RSSA testing without statistical differences between conditions (p=0.363). Afterwards during recovery, wearing or not wearing the CVJ, skin temperature was measured during the 1st, 3rd, 5th, 10th and 15th minute of the recovery period. Statistically significant differences were obtained after 3 and 5 minutes showing a faster skin temperature reduction using the cool vest (34.97±0.56 and 33.89±0.60, p=0.003 at minute 3; 34.22±0.31 and 33.59±0.54 p=0.025 at minute 5 for control and CVJ conditions respectively).

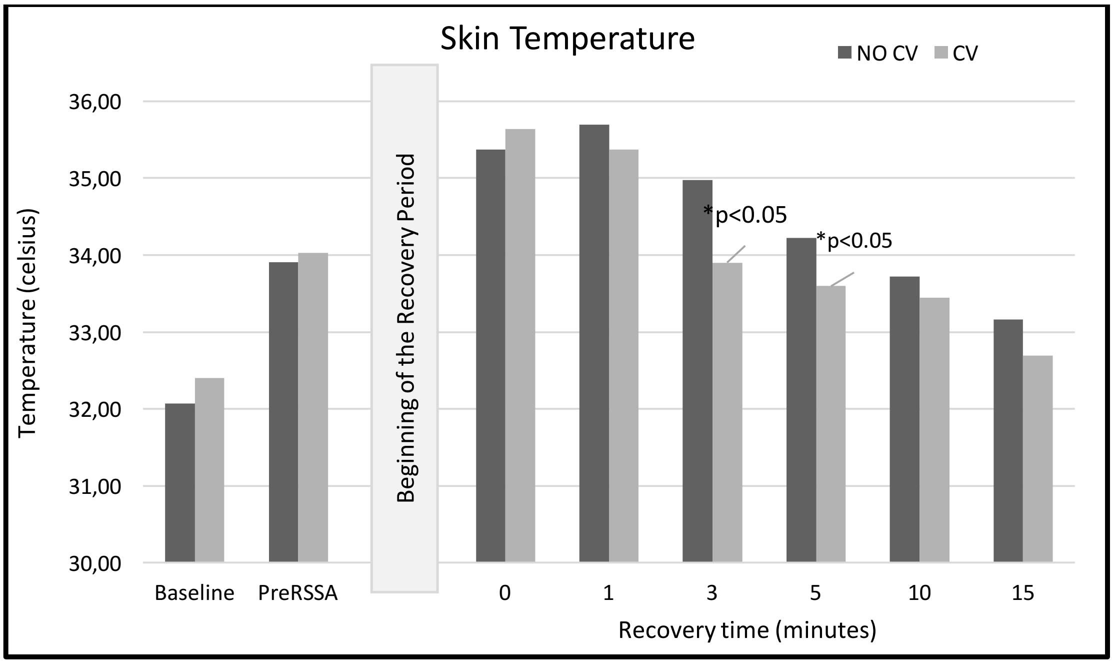


Figure 37. Skin temperature before and after the RSSA

Table 12 . Skin Temperature during the 15minute recovery period.

	No CV	CV	t	Sig. (2-tailed)
Baseline	32.07±0.80	32.40±1.02	0.602	0.560
Pre RSSA	33.91±0.54	34.02±0.55	0.500	0.628
		Beginning of the recovery period		
0	35.36±1.05	35.63±0.74	0.954	0.363
1	35.69±0.78	35.36±0.96	0.955	0.362
3	34.97±0.56	33.89±0.60	3.824	0.003*
5	34.22±0.31	33.59±0.54	2.629	0.025*
10	33.72±0.41	33.44±0.59	1.467	0.173
15	33.16±0.57	32.69±0.58	1.636	0.133

Date are mean ± SD. Temperature is expressed in Celsius degrees.

*Significance is set at $p<0.05$

The blood lactate concentration (LAC) achieved before the RSSA test and during the recovery period is presented in table 3. There was a high ICC between both testing days before the test, having a baseline ICC of 0.94 (0.87±0.46 mmol·l-1 for control day and 0.82±0.3 mmol·l-1 during cool vest day) and an ICC of 0.96 right before starting the RSSA test (1.59±1.09 mmol·l-1 and 1.52±0.77 mmol·l-1 without and whilst wearing the CVJ afterwards during the recovery period respectively).

There were significant differences for both days during the recovery period on LAC after the fifth minute (p=0.015) and the tenth minute (p=0.018), showing a faster reduction during the recovery wearing the CVJ.

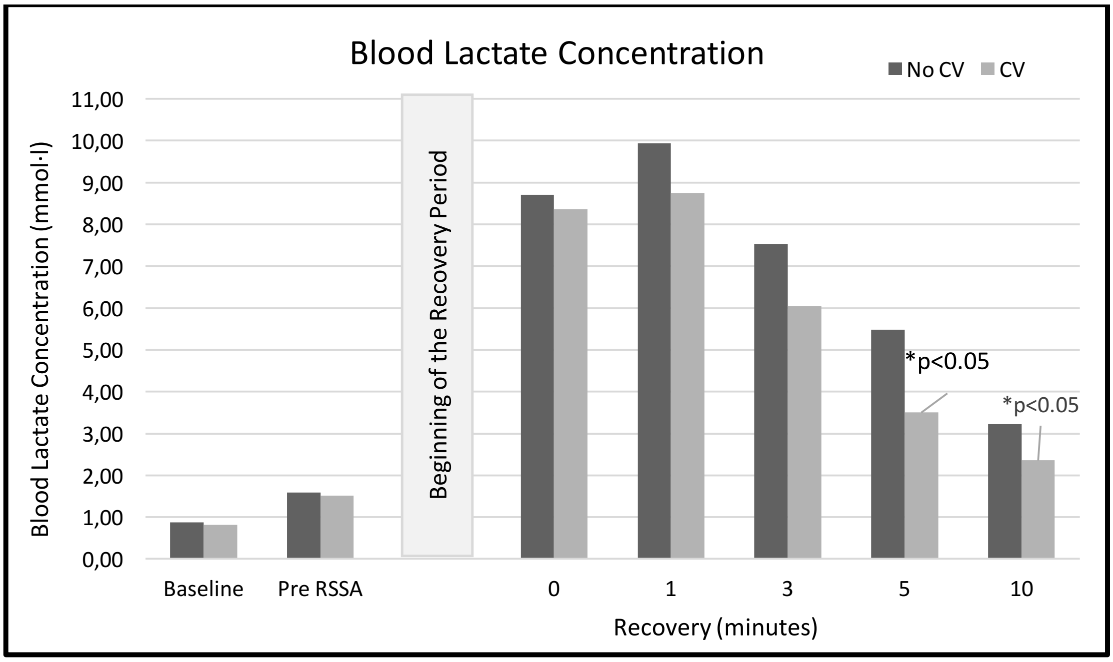


Figure 38. Blood Lactate concentration before and after the RSSA

Table 13. Blood Lactate Concentration

	No CV	CV	t	Sig. (2-tailed)	ICC
Baseline	0.87±0.46	0.82±0.34	0.821	0.431	0.94
Pre RSSA	1.59±1.09	1.52±0.77	0.677	0.514	0.96
Beginning of the recovery period					
0	8.69±1.99	8.36±2.42	0.396	0.700	
1	9.94±1.64	8.75±2.12	1.633	0.134	
3	7.53±2.08	6.04±1.84	1.689	0.122	
5	5.48±1.64	3.50±1.08	2.937	0.015*	
10	3.22±2.36	2.36±0.64	2.823	0.018*	

Date are mean ± SD. Blood Lactate concentration is expressed in mmol·l^{-1}
*Significance is set at $p<0.05$

Heart Rate Recovery (HRR) showed a high ICC (0.91) as a baseline measure every testing day, and a large ICC (0.60) right before RSSA test. A peak heart rate of 185 bpm was achieved right after the RSSA test in both of the testing days. There were significant differences after 1 minute of recovery (t=2.530; p=0.030) between recovery conditions showing a faster HRR for CVJ condition, while at 3, 5, 10 and 15 minutes of the recovery period there weren't any statistically significant differences found (t= 2.037 p=0.069, t=0.843 p=0.419, t=0.501 p=0.627, t=0.772 p=0.458 at 3, 5, 10 and 15 minutes respectively).

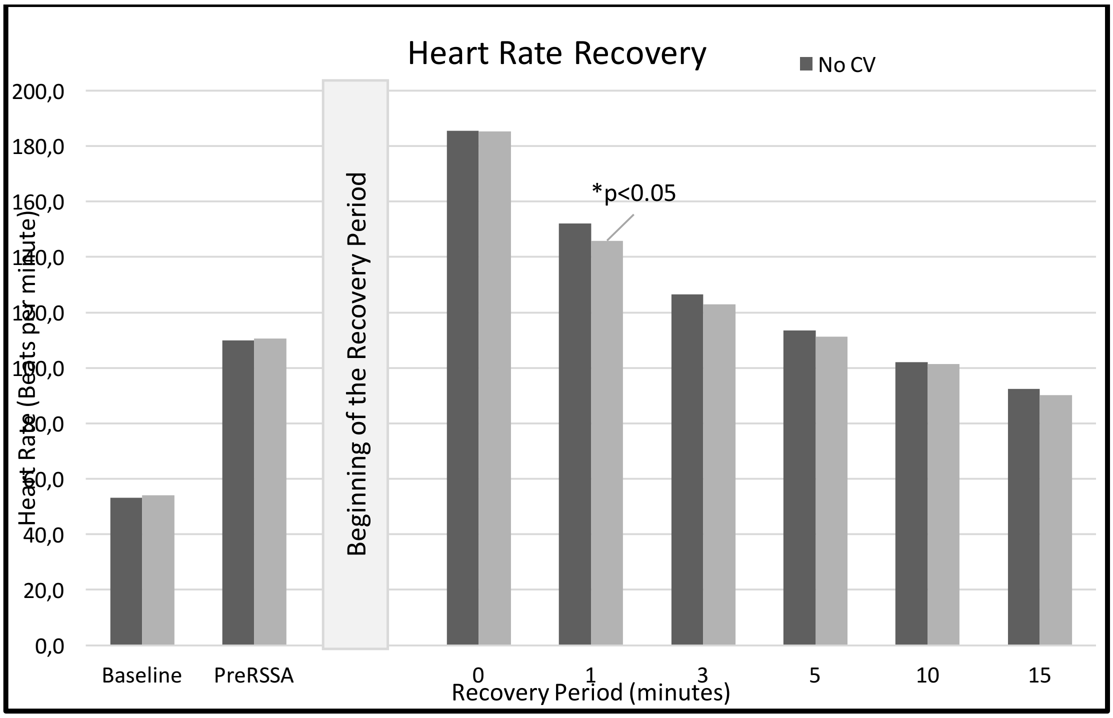


Figure 39. Heart Rate before and after the RSSA

Table 14. Heart Rate Recovery

	No CV	CV	t	Sig. (2-tailed)	ICC
Baseline	53.27±5.95	54.09±4.34	0.887	0.396	0.91
Pre RSSA	109.81±13.29	110.63±13.08	0.188	0.855	0.60
	Beginning of the recovery period				
0	185.45±4.43	185.18±2.89	0.213	0.836	
1	152.18±9.35	145.91±10.64	2.530	0.030*	
3	126.54±5.24	122.91±4.61	2.037	0.069	
5	113.54±6.69	111.36±7.32	0.843	0.419	
10	102±4.58	101.27±4.94	0.501	0.627	
15	92.45±6.02	90.18±5.63	0.772	0.458	

Date are mean ± SD. Heart rate is expressed in Beats per Minute

*Significance is set at $p<0.05$

7.5 Discussion

The aim of the present study was to examine the physiological effects of a cool vest jacket as a recovery method compared with a control, in their effect of lowering the skin and core temperature after intermittent exercise in warm conditions. We focused on a period of 10 minutes, trying to emulate the recovery period of a halftime of many sporting events. The main finding of the present study is that, according to our principal hypothesis, we identified a valid method to reduce skin temperature under heat stress conditions affecting physiological effects related to recovery (and possibly benefiting a subsequent performance) such as heart rate and blood lactate and after the RSSA protocol.

It's proven that performance in intermittent exercise under hot/warm conditions (30-40º) decreases compared to thermoneutral temperature environments (Drust et al., 2005; Morris et al., 2005; Sunderland et al., 2015). Because of the inability of the body to evaporate heat due to the high outdoor temperature, core body temperature rises inducing alterations in cardiovascular factors such as heart rate, blood pressure and arterial PCO2, ventilation and afferent feedback from the central nervous system influencing and hastening fatigue (Nybo, 2008; Nybo & Nielsen, 2001). Therefore, it's important to understand that different types of exercise intensity, duration and tasks, have different rates of core body elevation under warm conditions (Nybo et al., 2014).

We used RSSA as a test due to the validity indicated by match-related physical performance. The high intensity phases of the game have a large relationship with the physical capacities demanded during this RSSA test. Moderate but significant correlation has been found by Rampinini, Bishop, et al. (2007) and Impellizzeri et al. (2008) between sprinting (r=0.65) and high intensity running (r=0.60) completed during an official soccer game and the mean performance during the same RSSA test we used, proving this test to be reliable and applicable. As previously stated by Impellizzeri et al. (2008) and (Wragg et al., 2000) we also found RSSA mean is the parameter with the greatest reliability (0.85), while the last reliable is the percent decrement (0.62). As expected, the

RSSA protocol induced the participants into a fatigue state, reducing their performance by 4.92% and 4.84% (day 1 and 2, respectively), increasing their blood lactate concentration to at least 8 mmol·l-1. This results on fatigue effects of repeated sprint ability and intermittent exercise under heat stress conditions were similar to previous researches from other authors (Buchheit, Bishop, et al., 2010; Chen et al., 2015; Dellal et al., 2010).

Our research revealed that the use of a cool vest jacket after an RSA protocol under warm conditions aided in accelerating the body's recovery process from heat stress, showing a reduction of physiological and perceptual strains. A cool vest jacket is an easy to use cooling method, and ideal to use between bouts of exercise, recovery during game breaks and halftimes (P. A. Bishop et al., 2008; Nedelec et al., 2012). One of the main goals of a recovery method during a halftime of a soccer game is the capability of being easy and practical to use, this way coaches or technical staff can do their tactical modifications surrounded by all the players using this recovery method (Barnett, 2006; Reilly et al., 2005). The complexity of cold water immersion or whole body cryotherapy methods used during a half time and the possibility of impairing power generation through metabolic mechanisms because of the analgesic cooling effects are some of the reasons why these aren't common methods during halftime, although they are among the most used at the end of many sport events (Banfi et al., 2010; Hohenauer et al., 2015; White et al., 2013).

The statistical significance ($t=3.824$ $p=0.003$) of the cooling effect showed a faster lowering rate of the skin temperature after 3 and 5 minutes ($t=2.629$ $p=0.025$) during the 15-minute recovery when the cooling vest jacket was applied in a warm environment. Heat is removed from the body because of the superficial cooling effect on the skin surface, enhancing the blood flow circulation, hence cooling the peripheral blood before returning to the core of the body to cool core temperatures (Chan et al., 2017; Cleary et al., 2014; Yeargin, Casa, McClung, et al., 2006).

After intermittent exercise fatigue is created due to changes in the muscle and waste products of anaerobic metabolism such as lactic acid (Bangsbo, 1994; Ekblom, 1986). Lactate accumulation restrains muscle contraction and causes fatigue (Eniseler, 2005; Gharbi et al., 2014), hence a fast recovery from exercise is a key factor on performance (Nedelec et al., 2012; Robineau et al., 2012; Thomas et al., 2017). A RSSA test with a number of repetitions, around 5 to 6, achieve the goal of replicating the lactate observed during a game (Gharbi et al., 2014; Girard et al., 2011). Cooling seems to improve the rate of recovery significantly, reducing the concentration of blood lactate during recovery and allowing a higher muscle blood flow. It seems probable that the cooling factor of the peripheral blood or the activation of the parasympathetic system while wearing a cool vest has an ergogenic benefit on returning to the normalization of the physiological functions, returning to homeostasis replenishing energy stores faster (P. A. Bishop et al., 2008; Jeffreys, 2005).

It's difficult to compare intervention because of the duration of recovery times, temperatures and type of cryotherapy methods. Nevertheless, the results have been contradictory, finding that active recovery reduced blood lactate concentration levels more than cryotherapy (Vaile et al., 2008), or demonstrating a faster reduction using cold water immersion (Crowe et al., 2007). Our study shows similar baseline and peak LAC than Nakamura et al. (2009) and, as expected, an increment of LAC levels right after intermittent exercise, probably due to the secretion of the lactate into the blood, but after the first minute it seems to reveal a faster lactate removal, especially during the first 5 minutes of the CVJ application compared with control conditions ($p=0.015$, 5.48±1.64 mmol·l-1 and 3.50±1.08 mmol·l-1 for control and CVJ conditions respectively). The mechanisms responsible for the reduction of lactate after using a cool vest jacket or any type of cryotherapy method are not clear. Although some theories state that it might reduce muscle damage decreasing blood permeability and lymph vessels due to an attenuated inflammatory response (Ihsan et al., 2016; Pointon et al., 2012; Roberts et al., 2014).

Another usual response to intermittent exercise is an increase in heart rate to maintain an adequate cardiac output during exercise (DeMartini et al., 2011).

With the use of a cool vest jacket we also aimed to reduce their heart rate faster compared to normal conditions, in an attempt to trigger parasympathetic reactivation after exercise, mediated by the baroreflex facilitated by vasoconstriction and an increase in central blood volume, improving venous return and cardiac efficiency (Bleakley et al., 2014; Buchheit et al., 2009; Pump et al., 2001). Our participants showed an elevated heart rate after the RSSA protocol (185.3±3.6 Beats per minute) compared to their baseline levels (53.7±5.1Beats per minute). The baseline measures showed no significant differences between subjects and a very large correlation between both testing (0.91). Our study stated a significant difference (p=0.030) on HRR after a minute of recovery compared to control conditions. Previous research shows that HRR in the 1st minute post supra-maximal exercise is predominantly the result of sympathetic withdrawal, which is associated with the removal of stress metabolites (Borresen et al., 2008; Martinmaki et al., 2008; Perini et al., 1989), which might have an ergogenic benefit between bouts of exercise under warm conditions, rapidly improving or maintaining the athlete's performance. The remaining recovery heart rate outcomes looked more equalized between conditions during the rest of the recovery period which can have an ergogenic benefit between bouts of exercise under warm conditions, improving or maintaining the athlete's performance.

Our findings conclude that using a CVJ as a cryotherapy recovery method might reduce the impairment in performance after intermittent exercise such as a RSSA, thanks to the cooling effect on the athlete's body. It appears that wearing a CVJ after a protocol including 6 shuttle sprint repetition stimulates the parasympathetic system, accelerating recovery through a faster skin temperature reduction, blood lactate removal and a reduced heart rate, which might be beneficial in case of a subsequent bout of intermittent exercise. Given that the significant effects of a CVJ under heat stress appeared between the first and the fifth minute of the recovery period compared to control conditions, further investigation should be done aiming to find out if the recovery time can be shortened to assess performance in a subsequent bout of RSSA.

7.6 Conclusion

The favourable outcomes of our study give a hint about an effective method to stimulate recovery during a brief period of time or a halftime in a sport event. The effects of rapidly lowering the skin temperature in a hyperthermic athlete or an athlete participating in an event under warm conditions produce a faster decrement of heart rate and a reduction of blood lactate concentration combined with a better thermal sensation based on an improved rate of perceived excerption (Hornery et al., 2005; Sunderland et al., 2015) which might contribute to greater enhance of performance in athletic events.

This study only assessed the physiological effects of body cooling resulting in advantageous results, even though subjects might be dehydrated. Performance might increase if cooling is combined with proper hydration.

In conclusion, this study showed that passive rest under hot conditions wearing a cool vest jacket compared with control conditions, helps to reduce the physiological and cardiovascular strain produced by a high intermittent exercise protocol performed under heat stress conditions.

Chapter 8

General Discussion

8.1 Thermoregulation, exercise and the sample for the studies.

During exercise, core temperature is increased due to the elevation on heat storage. Total heat gain is greater than heat loss, hence there is an accumulation of heat storage (Flouris et al., 2015; Wendt et al., 2007). Also, muscles add heat due to the exercise elevation of metabolic rate, always proportionally depending on exercise intensity. The first body response to this core temperature rise is the increment of skin blood flow and sweating, in an intent to reduce heat storage and prevent a sudden increment in core temperatures (Flouris et al., 2015; Priego Quesada et al., 2015; Tansey et al., 2015). Modification of the blood flow circulation is one of the main physiological responses the body uses to dissipate heat. Metabolic heat is transported to the skin via blood, which will be convectively and radiative expulsed depending on thermal balance provided by core temperature and external temperature (Gonzalez-Alonso, 2012).

During situations of physical activity and heat stress, increment of body temperature and skin temperature lead to a cutaneous vasodilation that will ease the heat dissipation via convection of heat transfer and, more effectively, by evaporation of the sweat from the skin surface (Gonzalez-Alonso, 2012; Nybo et al., 2014).

However, another factor we had to consider was the individualized thermoregulatory response after a fatigue protocol of every subject. We decided to find a homogeneous sample of participants by selecting soccer players that have, at least, 3 days of practice a week including the match. Trying to find the ones with the same fitness level, we decided to use their VO_2 max as a common variable to select the participants in the study because cardiopulmonary fitness is often cited as an important performance characteristic (Fernandes Ade et al., 2016; Mora-Rodriguez, 2012). The Cooper test (Cooper, 1968) was performed two weeks before testing to estimate the participants VO_2 max, selecting those with a maximal aerobic power between 55 and 65 mL/Kg/min, this value being an average between what amateur and professional players demonstrate during laboratory testing (Ekblom, 1986; Reilly et al., 2000; Stolen et al., 2005).

The reason to find participants with similar levels is because of anthropometric differences, and because physical fitness and age might create different responses after the same fatigue protocol in the same environment. Body shape and mass contributes to a tendency to lose heat in cold environments, a large body mass helps to maintain a constant temperature because of a greater heat content compared to a small body mass (Budd et al., 1991). Also, body fat is important due to the thermal resistance to heat conduction from within the body, providing significant insulation against heat loss in the cold. Physical fitness might also vary individual response after exercise related to the indirect relationship with body fat, it's believed that people with a better level of physical fitness maintains warmer skin temperatures due to the thinner subcutaneous fat thickness and higher metabolic heat production compared to less fit (Formenti et al., 2013; Mora-Rodriguez, 2012). Age compromises the cold defense mechanisms by showing a slower response and temperature variation than young. The limitations in blood circulation increase the difficulty dissipating heat (Ferreira et al., 2008).

In our studies, we have tried to identify the body's temperature response during recovery after facing a fatigue-inducer protocol, in normothermic temperature (22±1.9°C and with a relative humidity of 30.8±4.8%) to study the effects of a cool vest jacket in mild temperatures on neuromuscular performance and responses on different soccer related skills and hot/warm conditions in a track and field facility (31.8±1.4° and 39±4.2% relative humidity with a wind effect of 1.2 m/s) to assess physiological responses after the use of the cool vest jacket. To minimize the effect of diurnal variations (Atkinson et al., 2010), we performed the test at the same time for all the participants, between 10 a.m. to 12 p.m. We expected to have two different skin temperature responses after the fatigue protocol.

8.2 Studies under normothermic conditions. Protocol and body temperature responses.

In our studies in normothermic conditions we used a fatigue inducer protocol on a treadmill based on the intensities determined and adapted from a study by Di Salvo et al. (2007), where they studied the "total distance covered in five selected categories of intensity, and the mean percentage of playing time spent in each intensity" of soccer players from the 1st Spanish soccer division teams and Champions league competitions, spent during the game. Those intensities were 6.5 km/h during 63% of the total time, 12.5 km/h for 14% of the time, 16.5 km/h for 15% of the time, 21 km/h for 5% of the time and 23 km/h for 3% of the total time. We randomized the intensities and duration during 45 minutes to create a fatigue state similar to a soccer game, also emulating the 5.5 km distance covered in one half of the match (Di Salvo et al., 2007). We are aware of the limitations of the study, our fatigue protocol doesn't involve change of directions or jumps, interactions with the ball or the opponent nor a cognitive fatigue. Nevertheless, we tried to approximate the levels of fatigue during a soccer game using the different running intensities in an acyclical manner.

The first thing we stated was the reduction of skin temperature after this running protocol is, starting at 32° and reaching an average of 29° at the end of the soccer running protocol on a treadmill. This is a common point with other authors that found exactly the same thermal response of the skin temperature; an initial decrease because of a blood flow redirection to the muscles involved in the action generated by a skin vasoconstriction reflex (Merla et al., 2010; Neves et al., 2015). Exercise induces the chemical energy into kinetic and thermal energy which ultimately triggers an increment in heat production, specially elevating heat in active muscles (Fernandes Ade et al., 2014). We hypothesize that when fatigue wasn't present the metabolic rate was working at a pace that the body was able to store heat and expel it using sweating, via convective heat transfer. When time and fatigue accumulate, the exercise-induced elevation of core temperature also increases skin temperature due to the inability to dissipate heat at the same rate than a less fatigued state. As long as this is a running protocol performed on a treadmill and length of strides depended on speed, Amano et al. (2016) found similar results after a running protocol with mixed stride frequency conditions, being more elevated the skin temperature and the sweat response than control conditions.

After the tests under normothermic conditions, skin temperature was below baseline levels (30.5±0.9°C, t=2.058 p=0.146), having a raising tendency during the recovery period to reach values above baseline levels. When exercise finishes, skin temperature increases due to a decrease in the vasoconstrictor activity and increased vasodilatory activity, working along with the nervous sympathetic system (Fernandes Ade et al., 2016; Johnson, 2010; Johnson et al., 2010). This response enhances blood flow circulation to the skin increasing heat dissipation to the environment with the objective to recover core temperature baseline conditions, which likely go above resting values during exercise (Nybo & Nielsen, 2001; Nybo et al., 2014).

8.3 Studies under hot conditions. Protocol and body temperature responses.

Our study performed under warm conditions had as a fatigue protocol a repeated shuttle sprint ability test consisting of a bout of 6 repetitions of 40 meter running, with a 180° turn after 20 meters, recovering 20 seconds between repetitions (Impellizzeri et al., 2008; Rampinini, Bishop, et al., 2007). This test has already been validated as reliable because it is comparable to the movement pattern required for team sport performance, as they are associated with high-intensity running distances performed during on-field soccer games (Impellizzeri et al., 2008; Nakamura et al., 2009; Rampinini, Bishop, et al., 2007).

We saw the opposite reaction on skin temperature in this study under warm conditions, compared with the study in normothermia. Although we didn't measure the process after every sprint repetition, the skin temperature after the RSSA protocol raised from an average of a baseline 32.20±0.9° to a 35.45±0.8° Celsius at the end of the RSSA protocol having the expected increment due to the high intensity anaerobic type of exercise (Merla et al., 2010; Neves et al., 2015). During high intensity exercise in the heat, body temperature rises faster than in normothermic conditions (Cleary et al., 2014; Sunderland et al., 2008), increasing the thermal strain experienced, thus decreasing performance faster than in normothermia, probably because of an impairment of the central nervous system function (Bain et al., 2015; Nybo et al., 2014). Once the heat content of the active musculature exceeds the core region, "the heat released in the muscle during cellular transpiration is transferred to the body core through conductive and convective heat exchange between the working muscle and blood, and from the working muscle to the surrounding tissues and compartments". Furthermore, central motor output is altered due to the reduction of cerebral blood flow and oxygenation (Nybo & Nielsen, 2001; Nybo et al., 2004). This affirmation confirms our results after the RSSA test, where the participants experienced an average RSSA performance decrement of a 4.9%. Under heat stress conditions, the hypothalamus, as responsible of thermoregulatory response, receives the thermoafferent signals and adjusts the thermoefferent responses as inhibitory signals resulting in decreased skills performance (Nybo et al., 2002; Rattray et al., 2015).

The participants finished the repeated shuttle sprint ability test above the baseline temperature (~35° Celsius,) and skin temperature slowly decreased until values below baseline. In this case, both environmental temperature and metabolic heat production have exceeded the body's ability to control and modify temperature through modulation of cutaneous vasoconstrictor activity. Consequently, as a sympathetic response, sweating evaporation is the most efficient way the body has to liberate heat to the environment. Meanwhile, "a neurogenic active vasodilation is initiated, allowing for the transport of heat from deeper tissue to the skin for its elimination" (Johnson et al., 2010; Johnson et al., 2014; Kellogg et al., 2007).

Although we didn't measure the degree of heat production or sweat loss during the fatigue protocol nor the recovery period, high rates of sweating might reduce central blood volume during exercise under hot conditions. Efferent and afferent feedback stimulate the cardiorespiratory centers of the of the brain stem influencing the control of mean arterial pressure (Journeay et al., 2005; Kenny et al., 2010; Shibasaki et al., 2006). Eccrine sweating is an effective method to reduce the rate body temperature rises during exercise and also a way to dissipate heat and reduce skin temperature while resting. The sweating response during exercise and/or during recovery is driven by changes in thermal factors such as skin and core temperature, and nonthermal factors, central command, baroreflex and muscle mechanoreceptors and metaboreceptors (Amano et al., 2011; Kenny et al., 2010). When exercise is finished, the nonthermal activity in central command is reduced at the same time feedback received by the muscle mechanoreceptors and metaboreceptors. Mean arterial pressure is also reduced and, even though physical activity has already ceased and a passive recovery is performed, skin blood flow and sweating are still under the baroreceptor influence (Carter et al., 2002; Journeay et al., 2005). Baroreceptors are directly involved in blood pressure location because of their location in the arterial walls of the aorta and internal carotid arteries. An activation of the vasosympathetic baroreceptor reflex induces a vasoconstriction of the arteries which, after the fall of blood pressure at the carotid sinus and aortic receptors, enhances a cardiosympathetic discharge to the sinus node and to the arteriolar vessels (Estañol et al., 2016; van den Munckhof et al., 2012). It looks like baroreceptors are mainly involved during passive recovery influencing skin blood flow and sweating when the athlete is inactive after physical activity, which might explain why the athlete kept sweating during recovery, even under temperate conditions.

8.4 Upper Body Cooling and its influence on fatigue and recovery.

The main objective of our studies was to modify the rate at which temperature was recovering to baseline levels during a short period of 15-minute time, trying to emulate the brief pause players have during a soccer game. One of the main purposes was to use a cool vest jacket to cool the upper body as an easy-to-use and cheap tool, to take advantage of the cryotherapy as a recovery method. Knowing that active recovery is not always possible during half times, because of the limitations of space and the need of time to modify tactical aspects by coaches, a cool vest jacket seemed a practical method to apply during this resting period.

There were different cooling locations and methods with the same characteristics as a cool vest jacket that have had different performance and physiological responses and might also be useful for the same purpose as ours. Neck cooling is one of them due to its proximity to the thermoregulatory center, the hypothalamus, and because of a high alliesthesial thermosensitivity (Cotter et al., 2005; Sunderland et al., 2015). It's been proven that neck cooling during exercise improves time trial running performance (Tyler et al., 2011; Tyler et al., 2010) and repeated sprint ability (Sunderland et al., 2015). Although the ability to complete complex cognitive tasks or improve the cognitive function is not clear (Ando et al., 2015; J. K. Lee et al., 2014). Physiologically, cooling the neck didn't have any effect on lowering mean skin temperature, heart rate, rectal temperature, sweat loss or lactate concentrations (J. K. Lee et al., 2014; Sunderland et al., 2015; Tyler et al., 2011).

Palm cooling is another cooling target that might enhance recovery after physical activity. There is a large vascular system in the palms of the hand, containing arteriovenous anastomoses with a rich vascular supply and a strong neural regulation that have a large effect on blood flow circulation controlling heat exchange with the environment (glabrous skin). We find glabrous skin on palms, soles, nose, lips and ears. The anastomoses produce fluctuations in skin blood flow under the influence of the adrenergic vasoconstrictor nerves. However, not all studies are in accordance with the benefits of palm cooling. Some researchers state an enhanced endurance performance in the heat after palm cooling (Kwon et al., 2015; Stevens et al., 2016), or delaying fatigue during resistive exercise (Caruso et al., 2015; Kwon et al., 2010) although unimproved running performance is also stated (Scheadler et al., 2013), and negative results reducing heat stress under hot conditions (Amorim et al., 2010).

We chose cooling the trunk through with the cool vest jacket amongst other cooling locations such as palm cooling or neck cooling, because of the different benefits it might have compared with cooling other parts of the body. In comparison with lower body, upper body has less efficient cardiovascular responses (Price et al., 2002; Sawka et al., 1982) which subsequently might accumulate a greater heat storage (Price et al., 2002), and accentuated vascular fluid shifts (Miles et al., 1983) and greater catecholamine production (Davies et al., 1974; Kjaer et al., 1987; Zouhal et al., 2008). Due to the larger surface area to mass ratio it is probably that greater heat loss might be expected. We resolved to choose a cool vest jacket as our cooling recovery method during all the studies because of its ability to contact a large skin surface area to maximize conductive cooling and increase heat transfer, hence incrementing skin blood flow, between torso and vest (from the skin to the surrounding microclimate) due to this difference of temperature gradient. As a consequence, we hypothesized that lowering the torso skin temperatures with a cool vest jacket would facilitate dissipating heat from deeper regions of the body through giving a greater afferent input. Therefore, achieving cooler skin temperatures also means that less of the total cardiac output is directed toward the skin, possibly allowing more blood to be directed to active skeletal muscle which might improve oxygen delivery and metabolite removal, thereby increasing power output.

Skin thermosensors provide an afferent signal to the hypothalamus to adapt the homeostatic mechanisms to keep the body working at an optimal core temperature. During exercise, these afferent inputs of heat increments, regulate the efferent response regulating vasomotor tone (convective cooling) and sudomotor activation (evaporative cooling). We hypothesized that by cooling the upper body we were giving an input to the thermosensitive afferents, inducing a faster response from the thermosensitive efferent enhancing the cooling mechanisms of the body, and the parasympathetic response.

8.5 Effects of the Cool Vest Jacket under normothermic conditions

8.5.1 Skin Temperature

Our studies in normothermia showed a significant response during recovery using the cool vest jacket compared to control conditions. While there weren't differences in skin temperature between conditions the first 10 minutes (t= 0.927 p=0.36, 32.04±0.98°C and 32.33±1.96°C, for experimental and control group respectively), the application of the cool vest jacket in the upper body seemed to have an ergogenic benefit with a significant effect from the tenth to the fifteenth minute of the recovery period compared to control conditions, effectively reducing skin temperature, meanwhile the control group kept increasing cutaneous temperature (t=3.965 p<0.005, 31.53±0.87° and 32.40±0.51 Celsius, cool vest and control group respectively). As explained before, skin temperature rises after exercise to reach baseline levels through radiation and convection. The cooling vest jacket didn't evade this physiological response for the first 10 minutes of the recovery period, although beyond this moment the control group's skin temperature kept raising at a slower rate than before and the participants that used the cool vest jacket to recover experienced a reduction of their skin temperature. A parasympathetic response might have taken place with a skin vasoconstriction reflex, resulting from the fastest cooling of peripheral system and a redirection of the blood flow circulation from the skin to active and fatigued muscles in an attempt to aid recovery. Although is not the fastest method to reduce skin temperature, cryotherapy (Bleakley et al., 2014; Hohenauer et al., 2015; White et al., 2013) and cold water immersion (Luhring et al., 2016; Mawhinney et al., 2017) have been proven to be more efficient in this issue, we focused on a method that didn't reduce muscle temperature leading to a probable reduction of performance (Crowe et al., 2007; Mohr et al., 2004) and muscle contraction (Bergh et al., 1979; Costello et al., 2012) increasing injury risk (Csapo et al., 2017; Herrera et al., 2010).

8.5.2 Fatigue recovery on neuromuscular function.

During our studies performed in normothermia, we focused on different performance responses after recovering 15 minutes with or without a cool vest jacket after a soccer fatigue protocol performed in a treadmill. Once we observed that the use of a cool vest jacket under normothermic lab conditions (22°) significantly reduced the skin temperature during a brief recovery period, we centered the subject of our study in some certain performance skills that some studies have demonstrated that are reduced during a soccer match such as jumping (Mohr et al., 2005; Wisloff et al., 2004), sprinting (P. Krustrup, Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., Bangsbo, J., 2003; Mohr et al., 2003; Rahnama et al., 2003), intermittent exercise (Bangsbo, 1994) or maximal force production (P. Krustrup, Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., Bangsbo, J., 2003; Rahnama et al., 2003; Wisloff et al., 2004). We hypothesized that wearing a cool vest jacket during the half time of a soccer match doesn't have any detrimental effect on some performance skills, furthermore, it may have some benefits on a subsequent performance during the second half of the match.

There were no significant differences, after the 15minute recovery period, in the interaction between control and experimental conditions in height during a countermovement jump (CMJ) (F= 0.330 p=0.573) and a drop vertical jump (DVJ) (p=0.422), in ground time contact during a DVJ (p=0.510), in time during a 30meter sprint (F= 0.183 p=0.674) or maximal speed during a 30meter sprint (F=0.585 p=0.456). Although none of these variables improved after using the CVJ during recovery compared with control conditions, there wasn't any reduction found in performance in the group that used the cool vest during recovery meanwhile the control group experimented a slight reduction of performance in jump height during the DVJ (p=0.048) compared to baseline conditions. It is already proven that cooling methods such as cold water immersion, lower limb immersion, whole body and local cryotherapy after exercise decreases metabolism, edema, circulation and responsiveness of the contractile system and increases resistance to movement (Bleakley et al., 2012; Muraoka et al., 2008; Mustalampi et al., 2012). Some studies state that the impairment of muscle performance after cooling has detrimental effects on nerve conduction velocity (Algafly et al., 2007), muscle spindle activity (Oksa et al., 2000), myotatic stretch reflex and ion (NA+, K+, Ca2+) and diffusion at the motor end plate (Bleakley et al., 2012; Rutkove, 2001). While as in performance skills such as the ones we performed, several studies have found negative effects on sprint and vertical jump with reductions of up to 2 cm in jumps and an average of 1 second on short sprints (Dixon et al., 2010; Fischer et al., 2009; Patterson et al., 2008; Richendollar et al., 2006).

Upper body cooling might also have psychological effects on subjects. Perceived exertion thanks to thermal sensation have been proven to be lower after the use of diverse cooling methods (Hornery et al., 2005; Vaile et al., 2008). Although results from other studies are not conclusive, participants felt better after cryotherapy (Bleakley et al., 2014; Costello et al., 2012; Hohenauer et al., 2015) applied directly to their lower extremities, despite the negative effects (aforementioned) of muscle temperature reduction. With cold water immersion (De Nardi et al., 2011; Luhring et al., 2016; Mawhinney et al., 2017), the sensation of pain is reduced, helping the athlete to have a better self-perception leading to a greater sensation of efficacy before starting a posterior exercise (Al-Nawaiseh et al., 2016; Stacey et al., 2010; Vaile et al., 2008). Despite not improving performance, a direct influence into the athlete's well-being perception might have been taken into account due to the psychological influence of a thermal agent in a subsequent performance (Barnett, 2006; Hornery et al., 2005) thanks to a positive mental and emotional response to exercise induced hyperthermia.

We did find significant differences in one of the soccer skills we assessed during one of our studies in normothermia. We found statistical differences in the interaction of shooting performance after recovering with a cool vest jacket (F=6.746 p=0.019). This neuromuscular test assessed a shooting maximal speed without relying on accuracy (the goal was at 2 meters' distance from the shooting point), which is decreased around an 11-13% after an incremental running fatigue protocol (Radman et al., 2016) to maximize power. It looks like passive rest reduces the capacity of the muscle to perform a rapid contraction and kick the ball with the same power as before meanwhile the cool vest group maintained the same performance. Some studies confirmed that after a soccer related fatigue protocol, shot speed is decreased compared to baseline levels and the first part of a match (Radman et al., 2016; Russell et al., 2011).

8.5.3 Fatigue recovery and Biceps Femoris contractile properties.

The application of cold is able to alter nerve conduction velocity (Algafly et al., 2007; Herrera et al., 2010). Pain reduction, the inhibition of nociceptors, muscle spasms and metabolic enzyme activity levels are a consequence of a cryotherapy method applied on the athlete that directly affects the efferent response (Airaksinen et al., 2003). On one side, force production and velocity is affected by cryotherapy reducing the velocity to produce the same force as thermoneutral conditions, thus a slower muscle contraction velocity, probably explained by slower cross-bridges cycling (De Ruiter et al., 2001; S. Racinais et al., 2010). It's been suggested that the exchange between Ca2+ and Na+ in neural cells is affected by this reduction of temperature (Bleakley et al., 2012; Reid et al., 2002), which might "increase the friction between Ca2+ and its cellular gate during the exchange that could result in the delay of action potential generation" (Algafly et al., 2007). Although previous research states that cooling application might slow nerve conduction, the application of a cool vest jacket might show a different response. The spinal cord thermosensitivity activates different afferent signals depending on the temperature perceived, subsequently sending information to the hypothalamus to send an efferent response to regulate body functions to control the homeostasis. The large upper body skin surface covered by the cool vest, especially the back, leaning on the skin surface above the spinal cord may trigger the cold signals sent by the cutaneous thermoreceptors and by the spinal cord neurons, which may also include signals from deep body regions such as the abdomen (Brock et al., 2016; McKemy, 2005). These signals sent by the skin thermoreceptors and spinal cord might enhance the afferent signal to suppress the cardiac sympathetic activity and increase parasympathetic output due to the arterial baroreflex activation (Pump et al., 2001; Shibahara et al., 1996).

Tensiomyography is a technique that is able to assess the contractile muscle capacity assessing the muscle displacement of the stomach muscles during an external electrical induced contraction (de Paula Simola et al., 2015; Rusu et al., 2013). We found that the participants who used the cool vest as a recovery method maintained the same contraction velocity to reach a greater muscle contraction, compared to baseline conditions, meanwhile the control group saw their muscle displacement reduced after a passive seated rest (F=4.690 p=0.039). We found a different output from another study that used cold water immersion (Garcia-Manso et al., 2011), who found a progressive reduction of muscle displacement after the immersion, meanwhile and similar to our findings, contraction velocity and muscle response time was not significantly modified after the different immersions. These results go in accordance with the rest of the neuromuscular studies. The participants who did the passive 15minute rest, maintained or decreased their performance in the posterior tests, meanwhile the participants who used the cool vest as a recovery method also maintained their baseline results or even experimented a benefit on performance in tests such as the DVJ and shoot performance.

8.5.4 Fatigue recovery on a drop vertical jump landing posture.

In our last test under normothermic conditions we assessed the capacity of the athlete to maintain the same landing posture during the force absorption and force production phases of a DVJ, with special attention on the knees displacement from a frontal plane, after the same running protocol we used for the previous studies. The ability of an athlete to absorb and produce maximal peak force during a sport event has a response on performance and it's an important feature on assessing the risk of an injury (Alentorn-Geli et al., 2014a; Norcross et al., 2013). Fatigue clearly affects landing biomechanics, decreasing the muscle's ability to respond to proprioceptive stimuli requiring longer times to stabilize the body after landing, increasing valgus displacement and knee extension during the force production phase, thus contributing to increase stress on the ACL (Fox et al., 2016; Nilstad et al., 2015). The kinematic study of the Frontal Projection Plan Angle (FPPA) of either dominant and non-dominant knee after the fatigue protocol and the recovery period either using or not using a CVJ reported significant differences during the eccentric phase of the DVJ using the CVJ ($p=0.048$ and $p=0.046$, dominant and non-dominant knee respectively), showing a valgus tendency during the absorption phase assessing the initial contact point (IC) until the maximum peak knee flexion (MAX), meanwhile the control group values remained unmodified compared to baseline conditions. Relating this kinematic result to the jump height performance in the force production phase, the DVJ, jump's height remained unchanged for the experimental group who counteracted the fatigue effect with a valgus knee displacement to jump as high as before without modifying their ground time contact either, while control group reduced their performance in the height's DVJ despite their FPPA during the eccentric remained the same as baseline conditions. It's most likely that muscle's fatigue state wasn't able to compensate the effects of fatigue trying to achieve a greater force momentum which might create an unstable moment for the knee due to the inability of the knee supporting muscles to cope with the effects of fatigue and the necessity of maximum performance at the same time. The ability of the CVJ to lower the blood temperature send to the skin by the central command faster than normal condition, giving the autonomic nervous system a main role during recovery.

8.6 Effects of the Cool Vest Jacket under hot conditions

We also expected significant differences during our study under warm conditions. The aforementioned fatigue protocol consisting on a RSSA, induced the participants into a fatigue state. During recovery, we found statistical differences supporting the use of a cool vest jacket after a RSSA to enhance recovery in heart rate recovery and blood lactate concentration.

8.6.1 Skin Temperature

We also assessed the effectiveness of the cool vest jacket in our study under hot conditions. As expected, the cool vest jacket rapidly reduced skin temperature of the participants compared to control conditions, showing statistically significant differences at the third minute of the recovery period ($t=3.824$ $p=0.003$, 34.97±0.56° and 33.89±0.60° Celsius, for control and cool vest group respectively). We hypothesized that the low temperature of the cool vest jacket, in contact with the exercise-induced hyperthermia, would provide a convective gradient that rapidly cooled the skin, thus it would enhance physiological response activating recovery mechanisms on the participants. Our results agree with different studies using the cool vest jacket to rapidly reduce skin temperature on hyperthermic athletes (Brade et al., 2010; Chan et al., 2017; Lopez et al., 2008).

8.6.2 Heart Rate Recovery

During the first minute after the RSSA, we found significant differences ($t=2.530$ $p=0.030$) in heart rate recovery rate compared to control conditions during passive rest using a cool vest jacket. One of the objectives of using cryotherapy methods after intensive exercise is the parasympathetic reactivation (Hausswirth et al., 2013; Schaal et al., 2013), especially in hot conditions where parasympathetic activity is most reduced after intense exercise (Brenner et al., 1998; Buchheit et al., 2009). It's been demonstrated that cold water immersion (CWI) and whole body cryotherapy (WBC) after exercise induce a parasympathetic reactivation after the sympathetic increment during intense physical activity, allowing a faster recovery (Bouzigon et al., 2016; Costello et al., 2015; Zalewski et al., 2014). The CVJ as a cooling stimulation method directly affects the cold cutaneous receptors located upper body in the chest and back, thus the spinal cord, "exciting the sympathetic α-adrenergic fibers, responsible for a peripheral vasoconstriction mechanism through the release of norepinephrine" (Hausswirth et al., 2013). Furthermore, fast heat dissipation is enhanced, resulting in a shift in blood volume toward the core, activating the baroreflex activity due to an increment in central pressure (Shibahara et al., 1996), thus reducing heart rate (Al Haddad et al., 2010).

8.6.3 Blood Lactate Concentration

Also, we found that Blood lactate concentration was being removed at a faster rate after 5 minutes than the control group (t=2.937 p=0.015). The cardiovascular strain during recovery is reduced as a result of a faster heart rate recovery rate and, followed-up by an increment of central blood volume and flow, the athlete might enhance his ability to remove waste products such as lactate. One of the effects of vasoconstriction after the application of the CVJ is the limitation of vessels permeability due to the attenuation of the inflammatory processes. A lower core temperature may inhibit blood lactate accumulation and increase lactate threshold (C. C. W. G. Bongers et al., 2017; James et al., 2015). One explanation might the inability of creatine kinase to diffuse into de lymph vessels due to this reduced permeability induced by the effects of cooling, reducing also the rate of creatine kinase efflux from the muscle (Ascensao et al., 2011; Wilcock et al., 2006). All these physiological changes produced by the cooling effect of the CVJ during the resting period contribute to the increased removal of metabolic byproducts, such as blood lactate, with the potential for enhancing recovery from intense exercise (Wilcock et al., 2006).

To summarise, we can affirm that the use of a CVJ after intense exercise either in normothermic or hyperthermic conditions contributes to a faster recovery to face a subsequent bout of exercise or second part of a game with similar conditions as before starting the activity. None of the different variables we assessed showed detrimental performances when compared to passive rest without a cooling method. We can assert that a cool vest jacket is an efficient way to improve physiological recovery of the athlete and an easy to use method that doesn't require a big or complex structure to use. Also, as a recovery method to use during recovery or halftime during a sports event, it allows freedom and mobility in case the athlete needs to attend the instructions of the coach, is relying in physical therapy or medical assistant compared to whole body cryotherapy or cold water immersion, methods that need the athlete to stay in the same place during the application time of the cooling method. This method has potential applications to improve physical performance and further investigations are needed to complement these findings to give guidelines to coaches, performance and medical staff to efficiently use this method during everyday practice and games.

Chapter 9

Conclusions

The intention of this thesis was to investigate the effects of a cool vest jacket during a passive rest period of 15 minutes after a fatigue inducer protocol in temperate conditions and under hot conditions. To the general objectives set before the thesis we can have the following conclusions:

GENERAL OBJECTIVE

- ✓ **Analyze the effectivity of a cool vest jacket after the fatigue protocol in normothermic conditions as a recovery method.**

SPECIFIC OBJECTIVES

- ➢ *Assess the effectivity of the cool vest jacket as a modifier of the body temperature in normothermia (Study 1).*

The cool vest jacket resulted in modifying the rate in skin temperature during the recovery period, attenuating the effects of temperature increment after exercise in normothermia (F=4.167 p=0.048), that might have induced a vasoconstriction and a faster reduction in skin blood flow.

- ➢ *Determine the effects of the cool vest jacket on performance recovery used during the recovery period on a countermovement jump, a drop vertical jump, a sprint and a shoot test (Study 2 and 4).*

The cool vest jacket didn’t seem to decrease performance compared to baseline conditions and a control group in a countermovement jump (F=0.330 p=0.573), 30-meter sprint (F=0.183 p=0.674), maximal velocity (F=0.585 p=0.456), except for ball kick power (F=6.746 p=0.019), where the control group reduced their ball kick performance. Meanwhile, the cool vest group maintained their baseline levels. Also, the control group reduced their performance in a drop jump height (t=1.795 p=0.048) and experimental group maintained their initial levels.

- *Evaluate the effects of the cool vest jacket on the contractile response properties of the Biceps Femoris after the fatigued protocol (Study 3).*

The contractile responses after the fatigue protocol and the application of the cool vest seemed to modify the interaction between cool vest and control group in muscle displacement (F=4.690 p=0.039) and contraction velocity (F=4.589 p=0.041), where the control group reduced their maximal displacement and contraction velocity. Meanwhile cool vest group maintained their baseline values.

- *Differentiate the effects of the cool vest jacket on the kinematics of a drop vertical jump and its effects on valgus and varus alignment during the eccentric phase (Study 4).*

There were differences found during the initial contact and peak eccentric phase of the drop vertical jump, finding a tendency of the cool vest group to a valgus alignment in dominant and non-dominant leg (p=0.048 and p=0.046 dominant and non-dominant respectively).

GENERAL OBJECTIVE

- ✓ **Confirm the effectivity of a cool vest jacket after the repeated sprint shuttle ability protocol as a recovery method under hot conditions.**

SPECIFIC OBJECTIVES

- ➢ *Assess the reduction rate effectivity of the skin temperature wearing the cool vest jacket compared to control conditions (Study 5).*

A higher reduction of skin temperature was found in the cool vest condition compared to control after 3 minutes (t=3.824 p=0.003) and 5 minutes (t=2.629 p=0.025), confirming the faster cooling rate using the cool vest.

- ➢ *Evaluate the effects of wearing the cool vest jacket on heart rate recovery and blood lactate concentration (Study 5).*

The physiological measures observed, stated the same tendency. Cool vest heart rate recovery rate had a faster reduced value after 3 minutes (t=3.824 p=0.003) and 5 minutes (t=2.629 p=0.025). The same thing happened to blood lactate concentration after 5 (t=2.937 p=0.015) and 10 minutes (t=2.823 p=0.018), showing a faster lactate removal the day the participants used the cool vest jacket as a passive recovery method.

Chapter 10

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Appendices

INEFC Institut Nacional d'Educació Física de Catalunya

Generalitat de Catalunya

Universitat de Lleida

DOCUMENT DE CONSENTIMENT INFORMAT

Persona Responsable de l'estudi: Dr. FRANCISCO CORBI SOLER, professor titular de l'Institut Nacional d'Educació Física de Catalunya. Investigador participant: Sr. CARLES LORENTE GONZÁLEZ, llicenciat en Ciències de l'Activitat Física i l'Esport (INEFC-LLEIDA) i cursant el Màster de Rendiment, Tecnificació i Alt Nivell (INEFC-BARCELONA). Aquest estudi forma part de la tesina final de màster que porta per títol: "***Efectes d'una armilla refrigerant en la funció neuromuscular en jugadors de futbol".***

Descripció del Procediment d'Estudi:
Aquest treball pretén estudiar l'efecte que pot tenir en les manifestacions explosives de la força la utilització d'una armilla refrigerant durant els 15 minuts de descans que el futbol té entre els dos períodes de joc que duren 45 minuts. Per tal d'avaluar aquest treball, es realitzaran diversos test en una única sessió d'estudi, on es mesurarà la força explosiva del tren inferior amb tècniques no invasives. Aquestes tècniques consisteixen en:

- Mesura de la velocitat d'acceleració amb cèl·lules fotoelèctriques, de la força elàstico-explosiva (CMJ) amb una plataforma de salts optojump i de la potència de xut amb un cinemòmetre Radar Stalker Pro.
- Control de la temperatura corporal amb un termòmetre de temperatura timpànica i de la temperatura cutània amb un termòmetre d'infrarrojos.
- Avaluació de la capacitat de re-equilibració mitjançant una plataforma de presions medicapteurs.

Amb aquest estudi es pretén determinar si fer servir una armilla refrigerant durant la mitja part d'un partit de futbol pot tenir efectes positius en la funció neuromuscular. Aquesta investigació no comporta cap incomoditat, dolor ni perill per la salut del participant. Amb la finalitat de familiaritzar-se amb els diferents elements de l'estudi, prèviament a la recollida de dades, es farà una xerrada explicativa on es realitzarà una demostració pràctica dels elements que s'utilitzaran.

El subjecte participant en aquest estudi:

- Podrà abandonar en qualsevol moment l'estudi de forma lliure i sense cap tipus de penalització.
- No es rebrà cap compensació econòmica ni en espècie per la seva participació en l'estudi.
- Un cop finalitzat l'estudi es rebrà una còpia dels resultats obtinguts.
- Totes les seves dades personals seran tractades de forma confidencial d'acord amb la Llei Orgànica 15/1999 de 13 de desembre sobre la Protecció de Dades de caràcter personal (LOPD)

- Podrà demanar en qualsevol moment informació sobre la seva participació en l’estudi o posar-se en contacte amb l’equip investigador a través de l’adreça electrònica: carloslorente1812@hotmail.com

Un cop llegit aquest document i atès a les explicacions i realitzacions realitzades declaro que jo____ __________________ amb DNI __________________________ essent major d’edat, he decidit participar de forma voluntària en l’estudi: “*Efectes d’una armilla refrigerant en funció neuromuscular en jugadors de futbol*” i declaro:

1) Que he llegit detingudament aquest document, discutint la informació presentada en ell.
2) El meu desig de participar com a subjecte d’estudi en aquest projecte acceptant les condicions descrites en el document annexa que s’adjunta.
3) Haver comprès en la seva totalitat la informació proporcionada en aquest document, així com els procediments que s’han de seguir durant la seva realització, les seves conseqüències i els possibles riscos de participar en ell.
4) Acceptar que les dades obtingudes en aquesta investigació poden ser publicades o difoses entre la comunitat científica o utilitzades com a material docent universitari, sempre amb finalitats no lucratives.
5) Haver rebut una còpia d’aquest document.

Consentiment: Després d’haver llegir i comprès l’objectiu de l’estudi, i haver resolt el(s) dubte(s) que tenia, dono la meva conformitat per participar-hi.

Jo, Dr Francisco Corbi Soler, en qualitat de responsable de l’estudi, he discutit verbalment el contingut d’aquest document amb el firmant amunt, explicant-li els riscos i els beneficis directament relacionats amb la seva participació aclarint els dubtes plantejats en relació a la comprensió d’aquest document o a la realització de l’estudi.

Lloc i data __________________________, a ________________ de ______________________ de 2013

Participant
Responsable

Nom i cognoms Dr. Francisco Corbi Soler
DNI:

INEFC Institut Nacional d'Educació Física de Catalunya
Generalitat de Catalunya

Universitat de Lleida

REVOCACIÓ DE PARTICIPACIÓ

Jo____
_________________________________amb
DNI______________________________________

Revoco el consentiment signat en data ____ i declaro no desitjar continuar en l'estudi titulat: "Efectes de la utilització d'una armilla refrigerant en la funció neuromuscular en jugadors de futbol" donant en aquesta data per finalitzada la meva participació.

Lloc i data_______________________________, a ___________ de ________________________ de 201____

Participant
Responsable

Nom i cognoms: Dr. Francesc Corbi
Soler
DNI:

INFORMACIÓ DE L'ESTUDI

Persona Responsable de l'estudi: Dr. FRANCESC CORBI SOLER, professor titular de l'Institut Nacional d'Educació Física de Catalunya.
Investigador participant: Sr. CARLES LORENTE GONZÁLEZ, llicenciat en Ciències de l'Activitat Física i de l'Esport (INEFC-LLEIDA), cursant el Màster d'Activitat Física i Salut (INEFC-BARCELONA) i el Doctorat en Activitat Física i Esport (INEFC-LLEIDA). Aquest estudi forma part del doctorat i de la tesina final de màster i porta per títol: "Effects of using a cool vest in the knee stability muscles response".

Descripció del Procediment d'Estudi:
Aquest treball pretén estudiar els efectes recuperadors que pot tenir en els músculs implicats en l'estabilitat del genoll la utilització d'una armilla refrigerant utilitzada durant 15 minuts en els que el participant, després d'un protocol màxim de fatiga, es manté assegut i descansant. Per tal d'avaluar aquest treball, es realitzaran diversos test en una única sessió d'estudi, on es mesurarà la resposta muscular del bíceps femoral i l'acció dels músculs estabilitzadors del genoll amb tècniques no invasives. Aquestes tècniques consisteixen en:

- Mesura de la contracció muscular amb un Tensiomiògraf.
- Mesura de la sol·licitació lligamentosa amb videogrametria.
- Mesura de la capacitat de salt amb una plataforma de contactes.
- Control de la temperatura corporal amb un termòmetre de temperatura timpànica i de la temperatura cutània amb un termòmetre d'infrarrojos.

Amb aquest estudi es pretén determinar si fer servir una jaqueta refrigerant durant 15 minuts pot tenir efectes positius en els músculs que intervenen en l'estabilització del genoll.
Aquesta investigació no comporta cap incomoditat, dolor ni perill per la salut del participant. Amb la finalitat de familiaritzar-se amb els diferents elements de l'estudi, prèviament a la recollida de dades, es farà una xerrada explicativa on es realitzarà una demostració pràctica dels elements que s'utilitzaran.

El subjecte participant en aquest estudi:
Podrà abandonar en qualsevol moment l'estudi de forma lliure i sense cap tipus de penalització.
No es rebrà cap compensació econòmica ni en espècie per la seva participació en l'estudi.
Un cop finalitzat l'estudi es rebrà una còpia dels resultats obtinguts.
Totes les seves dades personals seran tractades de forma confidencial d'acord amb la Llei Orgànica 15/1999 de 13 de desembre sobre la Protecció de Dades de caràcter personal (LOPD)
Podrà demanar en qualsevol moment informació sobre la seva participació en l'estudi o posar-se en contacte amb l'equip investigador a través de l'adreça electrònica: clorente@outlook.com

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DOCUMENT DE CONSENTIMENT INFORMAT

Un cop llegit aquest document i atès a les explicacions i realitzacions realitzades declaro que jo ____ amb DNI ________________________ essent major d'edat he decidit participar de forma voluntària en l'estudi: "Effects of using a cool vest in the knee stability muscles response" i declaro:

Que he llegit detingudament aquest document, discutint la informació presentada en ell.
El meu desig de participar com a subjecte d'estudi en aquest projecte acceptant les condicions descrites en el document annexa que s'adjunta.
Haver comprès en la seva totalitat la informació proporcionada en aquest document, així com els procediments que s'han de seguir durant la seva realització, les seves conseqüències i els possibles riscos de participar en ell.
Acceptar que les dades obtingudes en aquesta investigació poden ser publicades.
Haver rebut una còpia d'aquest document.

Consentiment: Després d'haver llegir i comprès l'objectiu de l'estudi, i haver resolt el(s) dubte(s) que tenia, dono la meva conformitat per participar-hi.

Jo, Sr. Carles Lorente González, en qualitat d'investigador en formació, he discutit verbalment el contingut d'aquest document amb el firmant amunt, explicant-li els riscos i els beneficis directament relacionats amb la seva participació aclarint els dubtes plantejats en relació a la comprensió d'aquest document o a la realització de l'estudi.

Lloc i data _______________________, a ______________ de ____________________ de 2014

Participant   Responsable

Nom: Dr. Francesc Corbi Soler

DNI:

REVOCACIÓ DE PARTICIPACIÓ

Jo____
_________________________________amb
DNI______________________________________

Revoco el consentiment signat en data ____ i declaro no desitjar continuar en l'estudi titulat: "Efectes d'una jaqueta refrigerant en activitats explosives específiques del futbol" donant en aquesta data per finalitzada la meva participació.

Lloc i data_______________________________, a ___________ de ________________________ de 2014

Participant Responsable

Nom: Dr. Francesc Corbi Soler
DNI:

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Generalitat de Catalunya
Universitat de Lleida

INFORMACIÓ DE L'ESTUDI

Persona Responsable de l'estudi: Dr. FRANCESC CORBI SOLER, professor titular de l'Institut Nacional d'Educació Física de Catalunya.

Investigador participant: Sr. CARLES LORENTE GONZÁLEZ, llicenciat en Ciències de l'Activitat Física i de l'Esport (INEFC-LLEIDA), Màster en Rendiment i Tecnificació a l'Alt Nivell i Màster d'Activitat Física i Salut (INEFC-BARCELONA) i cursant el Doctorat en Activitat Física i Esport (INEFC-LLEIDA). Aquest estudi forma part del doctorat i porta per títol: "Effects of using a cool vest in blood lactate after a RSA"

Descripció del Procediment d'Estudi:
Aquest estudi pretén estudiar els efectes que pot tenir el Cool Vest en la recuperació de l'esportista mesurant la concentració de lactat en sang, la freqüència cardíaca, la potència de xut i la capacitat de reequilibració:

- Mesura de la concentració de lactat en sang.
- Mesura de la potència del xut amb un Radar.
- Mesura de la reequilibració amb una plataforma d'estabilometria.
- Control de la temperatura corporal amb un termòmetre de temperatura timpànica i de la temperatura cutània amb un termòmetre d'infrarrojos.

Amb aquest estudi es pretén determinar si fer servir una jaqueta refrigerant després d'un protocol de RSA pot tenir efectes positius en la recuperació mitjançant l'anàlisi de la lactacidèmia.

Aquesta investigació no comporta cap incomoditat, dolor ni perill per la salut del participant. Amb la finalitat de familiaritzar-se amb els diferents elements de l'estudi, prèviament a la recollida de dades, es farà una xerrada explicativa on es realitzarà una demostració pràctica dels elements que s'utilitzaran.

El subjecte participant en aquest estudi:

- Podrà abandonar en qualsevol moment l'estudi de forma lliure i sense cap tipus de penalització.
- No es rebrà cap compensació econòmica ni en espècie per la seva participació en l'estudi.
- Un cop finalitzat l'estudi es rebrà una còpia dels resultats obtinguts.
- Totes les seves dades personals seran tractades de forma confidencial d'acord amb la Llei Orgànica 15/1999 de 13 de desembre sobre la Protecció de Dades de caràcter personal (LOPD)
- Podrà demanar en qualsevol moment informació sobre la seva participació en l'estudi o posar-se en contacte amb l'equip investigador a través de l'adreça electrònica: clorente@outlook.com

DOCUMENT DE CONSENTIMENT INFORMAT

Un cop llegit aquest document i atès a les explicacions i realitzacions realitzades declaro que jo____ __________________ amb DNI __________________________ essent major d'edat he decidit participar de forma voluntària en l'estudi: "Effects of using a cool vest in blood lactate after a RSA" i declaro:

6) Que he llegit detingudament aquest document, discutint la informació presentada en ell.
7) El meu desig de participar com a subjecte d'estudi en aquest projecte acceptant les condicions descrites en el document annexa que s'adjunta.
8) Haver comprès en la seva totalitat la informació proporcionada en aquest document, així com els procediments que s'han de seguir durant la seva realització, les seves conseqüències i els possibles riscos de participar en ell.
9) Acceptar que les dades obtingudes en aquesta investigació poden ser publicades.
10) Haver rebut una còpia d'aquest document.

Consentiment: Després d'haver llegir i comprès l'objectiu de l'estudi, i haver resolt el(s) dubte(s) que tenia, dono la meva conformitat per participar-hi.

Jo, Sr. Carles Lorente González, en qualitat d'investigador en formació, he discutit verbalment el contingut d'aquest document amb el firmant amunt, explicant-li els riscos i els beneficis directament relacionats amb la seva participació aclarint els dubtes plantejats en relació a la comprensió d'aquest document o a la realització de l'estudi.

Lloc i data _________________________, a ________________ de ______________________ de 2015

Participant Responsable

Nom: Dr. Francesc Corbi Soler
DNI:

INEFC Institut Nacional d'Educació Física de Catalunya
Generalitat de Catalunya
Universitat de Lleida

REVOCACIÓ DE PARTICIPACIÓ

Jo____
________________________________amb
DNI_____________________________________

Revoco el consentiment signat en data ____ i declaro no desitjar continuar en l'estudi titulat: "Efectes d'una jaqueta refrigerant en activitats explosives específiques del futbol" donant en aquesta data per finalitzada la meva participació.

Lloc i data______________________________, a ___________ de _______________________ de 201____

Participant Responsable

Nom: Dr. Francesc Corbi Soler
DNI: