The Effect of L-Menthol Application on Maximal Static and Dynamic Resistance Exercise Performance

Daniel Martin Over

Submitted in accordance with the requirements for the degree of Master of Science by Research

The University of Leeds

Leeds Trinity University

School of Social and Health Sciences

July 2020

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Acknowledgements

The work presented in this thesis would not have been made possible without the significant help and support of several individuals.

I would like to thank my head supervisor Dr Martin Barwood for his affirmation to my research and his cooperation throughout my research. He has been a fantastic support and given me guidance throughout the whole year. Most notably for the considerable amount of time he has spent, proofreading drafts, helping me with the analysis, ethical approval and the practical research elements of the rigorous study we have performed and completed over this past year.

Additionally, I would like to thank Mr Hendrickus Aben for his contribution and supervision through practical tests of this study. I would like to thank Mr Jordan Beaumont for his technical support throughout the experimental trials of the study.

Finally, I would like to thank my partner, Hannah Kirk for her support and encouragement throughout my studies.

Abstract

Introduction. L-Menthol spray application to the skin enhances exercise performance in the heat by improving thermal perception and lowering the rating of perceived exertion (RPE) through evoked sensations of skin cooling. Skin cooling has also been shown to increase the rate of force development during maximal isometric contractions potentially improving performance. Yet the effect of L-Menthol spraying has never been explored on maximal dynamic or isometric exercise performance. We hypothesised an L-Menthol spray would improve lifting performance, reduce RPE and alter muscle electromyography (EMG). **Method.** Twelve resistance-trained male participants (aged 24 ± 4 years, body mass: 75 ± 8 kg, height: 173 ± 7 cm), volunteered following ethical approval. They completed three laboratory visits: baseline to estimate one repetition maximum (1RM) and two visits during which maximal dynamic lifting (DLT: 75% of 1RM) and isometric maximal lifting (IMLT; 3 x 3-second dynamometer lifts) were performed with either prior spraying of the legs with L-Menthol spray or a control-spray (counter-balanced and double-blind). Key measures were: Weightlifting performance, RPE, EMG and thermal comfort (TC) and sensation (TS). Data were compared using t-test and ANOVA to 0.05 alpha level. **Results.** L-Menthol spray improved TS_{legs} in the IMLT ($p = .047$) and improved TC_{wb} in the IMLT ($p = .039$) (i.e. participants felt cooler and more comfortable) but felt no less exertion. DLT and IMLT performance were unaffected yet during IMLT, EMG activity of the rectus femoris was greater in the L-Menthol spray condition (grand mean ± SD; 3.49 ± 1.75 v and 4.36 ± 1.96 v; $f_{(1,11)} = 5.450$, $p = .040$, $\eta p2 = .331$, control-spray and L-Menthol spray, respectively). **Discussion.** L-Menthol spraying increased rmsEMG during isometric exercise implying greater muscle motor unit recruitment via the sensory-somatic neural pathway and activation of TRPM8 ion channel. L-Menthol spray may enhance the performance of longer duration static weight-lifting activities.

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List of Abbreviations

1RM	1 Repetition Maximum
5RM	5 Repetition Maximum
ANOVA	Analysis of variance
AU	Arbitrary unit
AUC	Area under the curve
BF	Bicep femoris
CNS	Central nervous system
DLT	Dynamic lifting task
EMG	Electromyography
HR	Heart rate
IMLT	Isometric Maximal lifting task
IMTP	Isometric mid-thigh pull
MG	Medial gastrocnemius
MPF	Mean power frequency
MN/(‘s)	Motor neuron/(‘s)
MU/(‘s)	Motor unit/(‘s)
MVC	Muscular voluntary contraction
PAR-Q	Physical activity readiness questionnaire
PNS	Peripheral nervous system
RFD	Rate of force development
RMS	Root mean squared

rmsEMG	Root mean squared electromyography
RPE	Rating of perceived exertion
RTT	Readiness to train
S and C	Strength and conditioning
SC	Skin cooling
SD	Standard deviation
SWU	Specific warm-up
TRPM8	Transient receptor potential melastatin 8
T_{skin}	Skin temperature
TS	Thermal sensation
TS_{wb}	Thermal sensation (whole-body)
TS_{legs}	Thermal sensation (legs)
TC	Thermal comfort
TC_{wb}	Thermal comfort (whole-body)
TC_{legs}	Thermal comfort (legs)
TT	Time trial
TTE	Time trial to exhaustion
VAS	Visual analogue scale
VL	Vastus lateralis
VM	Vastus medialis
WU	Warm-up

Chapter 1

1. Introduction

L-Menthol has been used in a diverse range of consumer products extending from toothpaste and shower gels to cold medications because of the enhancement to palatability and fragrance that L-Menthol gives (Eccles, 1994). L-Menthol is cyclic terpene alcohol formed from mint oils (Mentha piperita) and can also be prepared synthetically (Eccles, 1994). It is found in many dynamic forms of which L-Menthol produces the strongest cooling effects (Eccles, Griffiths, Newton & Tolley, 1988). L-Menthol evokes a variety of biological responses (Eccles, 1994) but predominantly acts on the sensory nerves (McKemy, Neuhausser, & Julius, 2002) provoking biological changes manifested as cooling sensations, which are evident when applied to the surface of the skin or internally (Watson, Hems, Rowsell, & Spring, 1978). When applied to the surface of the skin, L-Menthol stimulates human body temperature receptors in a comparable means to temperature change itself (Green, 1985). This is thought to be due to L-Menthol changing the activity of the highly sensitive cold receptor transient receptor potential melastatin 8 (TRPM8) which is situated on the cell membrane of the sensory neurons (McKemy et al, 2002; Peier et al, 2002; Kozyreva & Tkachenko, 2008). TRPM8 is in a sub-family of thermoreceptors which induce cool sensations and is activated by temperatures ranging from 8 to 28°C (Jordt, McKemy, & Julius, 2003; Peier et al, 2002).

L-Menthol has been introduced to several products which have claimed to accelerate rehabilitation or to improve athletic performance during exercise in hot and humid climates by topically applying to bandages and saturating L-Menthol into clothing and wristbands (Gillis, House, & Tipton, 2010). Subsequently, the perceptual effects of L-Menthol have become largely of interest to exercise scientists, focusing on improving endurance exercise performance. L-Menthol is commonly applied in warm ambient temperature environments

when unpleasant thermal perceptions are limiting exercise performance (Barwood, Corbett, White & James, 2012). Evidence suggests that exercise performance in hot conditions is impaired compared to exercising in cooler climates (Tucker, Marle, Lambert & Noakes, 2006) most recently shown in the women's world athletics marathon in Doha, Qatar which saw 28 of 68 athletes (~41%) fail to complete the race probably due to the extreme heat (30°C) and humidity. Spray application, one of the primary modalities of L-Menthol use, has been explored in several key studies (Barwood, Kupusarevic & Goodall, 2019; Barwood et al, 2012; Barwood, Corbett & White, 2014). These studies were based on the original investigation of Gillis and colleagues (2010), who explored L-Menthol application to the skin and clothing by surface spraying and found this modality to have a consistent perceptual improvement, making participants feel cooler and more comfortable, during endurance exercise in hot and humid conditions.

Studies which have examined the application of L-Menthol have explored moderate to low concentrations. Evidence suggests a concentration of up to 0.20% or lower minimises any meaningful changes in thermoregulatory response. Additionally, higher concentrations of L-Menthol have been shown to lead to heat gain responses being triggered (e.g. delayed sweating and vasoconstriction) (4.6%; Kounalakis, Botonis, Koskolou, & Geladas, 2010). Higher concentrations of L-Menthol increase the risk of heat-related illness (Gillis et al, 2010). There is consistent evidence to suggest low concentrations do not cause heat-related illness and a single application of L-Menthol to the skin significantly improves thermal perceptions in hot conditions relieving sensations of feeling too hot and uncomfortable for up to twenty minutes (Gillis et al, 2010).

In addition, other perceptual responses such as the rating of perceived exertion (RPE) have been used as a measure to explore the ergogenic effects of L-Menthol. Barwood, Corbett, Thomas and Twentyman (2015) examined the effect of L-Menthol spray application on

perception, including RPE, at a fixed power output. With the application of L-Menthol spray, it elicited a reduction in RPE compared with the control spray. The results showed a near significance at 12 km (p = 0.086), however, was significantly lower at 14 km (p = 0.038) and then at 16 km (p = 0.018) in the L-Menthol spray condition. The duration of the time trials (TT's) were 32.4 minutes (control-spray) and 32.7 minutes (L-Menthol spray). This provides evidence suggesting, using L-Menthol spray in other activities may be influential where RPE is a potential limiting factor to exercise performance. Potentially, this could include maximal and sub-maximal static and dynamic exercise performance as this has yet to be explored within the sporting literature in relation to these kinds of activities. For example, activities such as the deadlift exercise may be influenced by L-Menthol spray application and this could lead to an increase in weightlifting performance, reduced RPE and reducing the onset of fatigue in the context of exercise performance and training benefits.

An enhanced rationale for an application to weight lifting performance beyond the effects on RPE is shown by Shimose and colleagues (2014) who reported that skin cooling (SC) improves the rate of force development (RFD) at the early onset of muscle contraction by up to 17% which was seen by an increase of root mean squared electromyography (rmsEMG). This potentially could be due to selective excitation of motor neurons (MNs), via interneurons, from several forms of somatosensory input such as temperature, smell, touch, hearing and taste (Shimose et al, 2014). Given that L-Menthol also evokes and activates thermoreceptors in a similar manner to skin cooling, a similar effect on force development is conceivable; this has yet to be investigated. This could be specifically due to the selective ion channel TRPM8, previously mentioned, as it is the predominant thermoreceptor responsible for the cellular and behavioural response to cool temperatures and when activated converts thermal stimuli peripherally into neuronal activity (M Knowlton, & D McKemy, 2011). In summary, the

peripheral thermoreceptors sense cooling of the body when TRPM8 is activated by L-Menthol (Reid, 2005), which is discussed further in the literature review.

The effects of L-Menthol topical application have not been examined in explosive or static maximal and dynamic exercise conditions despite the evidence that L-Menthol has the potential to improve RPE, can relieve muscular fatigue and initiate peripheral muscular facilitation. In addition, a study conducted by Barwood and colleagues (2019) concluded that it is plausible that topical L-Menthol application could supply an ergogenic benefit in other activities, such as strength and power-based exercises, which could be limited by hot environments or perceptual mechanisms and correspondingly in relation to RPE. From the perspective of exercise performance, if L-Menthol does have ergogenic effects in this type of activity there may be a corresponding benefit to strength, power and training capabilities, although the latter will not be assessed in the present study. The findings of this project should be of interest to the research and sporting community.

Chapter Two

2. Literature Review

2.1 Chapter Overview

This chapter will outline the rationale for the research direction of the thesis. Firstly, a brief history of L-Menthol will be discussed in the early stages of the chapter. This will include how L-Menthol is produced, the modes of L-Menthol application and a brief insight into the potential exercise performance benefits of L-Menthol. Secondly, the review of literature will source through specific variables which have been observed to be influenced by L-Menthol and build the rationale for the present research conducted in this thesis. This will include, mechanisms of thermoregulation, thermal perceptions, RPE, electromyography and how L-Menthol interacts with these mechanisms and variables in exercise performance. This section

will also elaborate on L-Menthol's ability to potentially affect maximal strength exercise performance. Thirdly, the literature review will conclude by highlighting the gap in the literature and directing the focus onto the research conducted in this thesis. Finally, the chapter will summarise the aims and hypotheses of the research.

2.2 A Brief History of L-Menthol

Menthol is monocyclic terpene alcohol which is found in many essential oils (spearmint and peppermint) as it is a naturally occurring compound in a plant species called mentha which include the plants; Mentha Piperita which produces peppermint oil and mentha arvensis (corn mint oil), a Japanese mint which in addition, both produce a minty smell and flavour (Gelal, Jacob & Benowitz, 1999; Eccles et al, 1988; Eccles, 1994; Harris, 2006). There are over thirty compounds found in peppermint oil with a vast quantity being L-Menthol (33-60%) (McKay & Blumberg, 2006). The L-Menthol compound is extracted from the plant's origin by steam distillation (Eccles, 1994). Today, L-Menthol is a largely used substance around the world which has been rooted into a huge variety of our pharmaceutical and personal hygiene products, such as, toothpaste, mouth wash, shower gels, chewing gum, cigarettes, confectionery, candy, common cold medications, vapo-rubs, aromatherapy inhalation and chemical cooling agents (Green, 1992; Gelal, Jacob & Benowitz, 1999; Eccles, 2000). Regarding the purposes of L-Menthol as a medicinal product, it is available prescribed or over the counter for several conditions, such as musculoskeletal pain, respiratory conditions and gastrointestinal disorders (Eccles, 1994).

The characteristics of these commercially used products have a minty fragrance and have a common tendency to elicit strong cooling sensations, which is due to the specific L-isomer (L-Menthol) (Eccles, Griffiths, Newton, & Tolley, 1988; Gelal, Jacob & Benowitz, 1999). With this said, when applying L-Menthol to the skin it has been seen to exert strong cooling sensation

from stimulation of the skin and mucosal surfaces such as, the nose, mouth and lungs (Watson, Hems, Rowsell, & Spring, 1978), which is said to be ascribed to the stimulation of thermoreceptors (Golscheider, 1886). Furthermore, temperature sensation is produced by operative thermoreceptors which ensure the transportation of the signal of perception of temperature to the central nervous system (CNS) (Kozyreva & Tkachenko, 2008). Numerous studies over the years have researched cold sensitivity by analysing the cellular and molecular mechanisms activated by L-Menthol. It is evident that the thermosensitive TRP (thermo-TRP) channels (transient receptor potential), which are sensors of temperature change, are the chief sensors in the peripheral nervous system (PNS) when activated (McKemy, Neuhausser, & Julius, 2002; Voets et al, 2004). In addition to the TRP channels, as previously mentioned, TRPM8 (a member of the TRP family) has been stated to be the principal channel which is activated by cold stimuli and L-Menthol from temperatures between 8-28°C (Jordt, McKemy, & Julius, 2003; Chuang, Neuhausser, & Julius, 2004). TRPM8 is located in the dorsal root ganglia (Macpherson et al, 2006). However, it has been explored by Macpherson and colleagues (2006) that L-Menthol is not specific to the TRPM8 ion channel and has shown it has exploratory effects on other thermo-TRP ion channels, such as the activation of TRPV3 (subfamily V), which indicate other sensory compounds such as L-Menthol may have promiscuous relationships which other thermo-TRP's.

There has been extensive research into the history and effects of L-Menthol, as early as Goldsheider (1886) who hypothesised L-Menthol's primary ability to stimulate thermoreceptors via the skin (cooling sensations) and Hensel and Zotterman (1951) introduced the idea that L-Menthol explicitly acts upon the cold-sensitive fibres and can mimic cool sensations. However, it was not until McKemy and colleagues (2002) and Peier and colleagues (2002) found the identification of the TRP channel; TRPM8, which was found to be stimulated by both L-Menthol and cool to cold stimuli (8-28°C) (Patel, Ishiuji, & Yosipovitch, 2007).

From the birth of the early theories of L-Menthol and its continued research into the expanding practise of L-Menthol in commercially bought products, medicinal uses and exercise performance, it has become largely of interest to exercise scientists, of L-Menthol's perceptual and thermal perception benefits and its potential use as an ergogenic aid in exercise performance. However, it is important to understand the mechanisms with which L-Menthol interacts within the body.

2.3 Thermoregulation Mechanisms

L-Menthol is known to interact with thermoregulatory mechanisms; therefore, this section will first outline the basics of thermoregulation, how thermoregulation interacts with exercise performance and then outline how L-Menthol may interact with these two factors.

With the ability to sense thermal properties such as temperature and humidity, thermoregulation mechanisms provide humans with the awareness of the present thermal environment through thermal and wetness sensations (Shelford, 1918; Thomas, Siegelbaum, & Hudspeth, 2000). In addition, humans have specific sensory and somatosensory systems which can convert certain external stimuli, such as temperature into biological signals, caused by action-potential (Thomas et al, 2000). With the ability to encode sensory information, the body can respond or adjust thermal behaviours, such as taking action to make the environment more thermally comfortable, for example, opening a window or adding or removing clothes (Schlader, Stannard & Mündel, 2010). Essentially, thermoregulatory responses are initiated by thermal stimulation by the input of thermally sensitive thermoreceptors which are located peripherally in the skin, muscles and certain areas of the CNS (brain and spinal cord) (Romanovsky, 2007; Boulant & Bignall, 1973; Romanovsky, 2014). The thermoregulatory system controls body temperature and is dependent upon whether external stimuli are hot or cold, which initiates activation of the peripheral (skin and muscle) and CNS thermoreceptors,

ultimately specifying an autonomic response, for example, shivering or sweating (Filingeri, 2011). To summarise, the peripheral nerves in the skin and muscles are connected to the CNS (spinal cord, brain stem) via sensory pathways which allow electrical signals to be sent from the first initial temperature stimulant via the peripheral pathway (thermoreceptors in the skin and muscles) to the CNS, to the brain, which then determines the thermoregulatory behavioural response (Filingeri, 2011). This mechanism of thermoregulation has been observed and has been of interest to sporting literature on how this mechanism is affected during and by exercise performance.

2.4 Thermoregulation and Exercise Performance

A study conducted by Tucker, Rauch, Harley and Noakes (2004) measured skin temperature (T_{skin}), rectal temperature, time to completion, power output and Electromyography (EMG) of ten male cyclists who performed one 20km TT at 35 degrees (hot) and one at 15 degrees (cool). Thermocouples were attached to the sternum region (chest), left mid-thigh, left calf and forehead to measure T_{skin} and were measured at every 5km interval, as was surface EMG and rectal temperature. The results showed T_{skin} of all four areas were significantly greater in the hot than in the cool conditions throughout the TT (p = <0.001), rectal temperature saw a significant increase over time (p = <0.001) between conditions, which the final temperature recorded (20km) in the hot condition was mean and standard deviation (±SD) 39.2 ± 0.6 °C compared with 38.8 ± 0.4 °C in the cool condition (p = <0.005), all other recorded intervals were not significantly different. Time to complete the 20km TT was significantly greater in the hot than in the cool condition (p = <0.001) and power output in the hot condition was correspondingly lower mean (±SD); 255 ± 47 W compared to 272 ± 45 W in the cool condition (p = <0.01). EMG amplitude was lower in the hot condition than in the cool condition at 10km and 20km (p = 0.05). These results, especially T_{skin}, associate strongly to the presence of a

central thermoregulatory system via the CNS as the thermoreceptors in the skin have sensed the sensory input of heat. This is generated from metabolic heat production in the working muscles which, if sensed as being excessive, may lead to decreased exercise intensity and reduced motor command in the working muscles to a state of natural equilibrium. In addition, the body will also limit exercise performance to reduce heat production and to prevent body temperature rising to harmful levels (hyperthermia) (Tucker et al, 2004). Hence the decrease in time to completion in the 20km TT and reduced power output in the hot conditions due to the significantly elevated skin temperatures. Similarly, Parkin, Carey, Zhao and Febbraio, (1999) studied the effect of ambient temperature on human muscle metabolism in fatiguing submaximal exercise. Eight endurance-trained men participated. A temperature-controlled chamber was used to sustain the three conditions: 3 °C (cold temperature, CT), 20 °C (Neutral, NT) or 40 °C (Hot, HT). Their results showed no significance of muscle temperature or rectal temperature was seen at rest between condition, however, saw higher muscle and rectal temperatures in the HT at fatigue compared with NT and CT (p = 0.05). Exercise time was longer in the CT condition than NT and HT (p = <0.05). This further supports the relationship between the thermoregulatory system and limiting exercise performance in endurance activities in hot conditions compared to cool ambient temperatures where exercise performance is not as limited when the body's peripheral system is exposed to cool environments rather than hot or warm environments.

2.5 Mechanisms of Skin Cooling and L-Menthol on Muscle Activity

As previously mentioned by Thomas and colleagues (2000), humans have a sensory-somatic nervous system which can convert temperature into biological signals. These signals are transmitted through to the CNS and produce signals to the muscles as action potentials which have the potential to adjusts motor commands and the thermoregulatory system during exercise

(Kayser, 2003). Interestingly, L-Menthol has been seen to interact with these neural pathways, utilising a similar mechanism to the one described above.

It has been discovered, thermo-sensory proteins which are part of the TRP ion channels are subjects in the PNS which are said to be able to specifically contribute to thermoregulation (Pogorzala, Mishra & Hoon, 2013; Caterina, 2007). These thermo-sensory proteins allow ion fluxes by a gating process through membranes which are said to be reliant upon temperature change which then contributes to the production of action-potential via temperature stimuli through nerve endings (thermoreceptors) (Viana, de la Peña & Belmonte, 2002). The TRP ion channel has a sub-group of channels, with each channel responding to a specific temperature range, which certain sensory compounds, such as L-Menthol, activate in a similar way to temperature change itself, such as a cold environment (without affecting T_{skin}). In the sub-family of TRP ion channels is the channel TRPM8 which has been seen to be the main afferent of cool temperatures between 8-28 °C (Filingeri, 2011; Jordt, McKemy, & Julius, 2003; Chuang, Neuhausser, & Julius, 2004). Previous literature has supported and proved the idea that along with temperature change, TRPM8 can also be activated via a specific chemical, L-Menthol (Caterina, 2007). As previously mentioned in the first few paragraphs of this paper, Hensel and Zotterman (1951) saw L-Menthol can mimic a cooling sensation without decreasing the temperature of the muscle or affecting the temperature of the skin. The mechanism in which L-Menthol acts upon is L-Menthol (when applied to the skin) stimulates the thermoreceptors in the skin (PNS) and activates the ion channel TRPM8 which mimics cool to cold sensations and sends feedback in the form of electrical signals via the sensory-somatic nervous system. The electrical signals are conducted through the CNS. The electrical signals are formed as action-potentials and it is proposed the TRP ion channels are strongly associated with being voltage-dependent gated (Voets et al, 2004). Within these TRP ion channels, it is suggested ion fluxes occur via gated control through membranes and this influx consists of

calcium ions which is the chemical which is vital in the regulation of cellular processes including muscle contractions (Endo, 1977). It is said TRPM8 acts similarly to other Lingard gated channels, demonstrating rapid activation of action potentials which travel through MN's (Chuang, Neuhausser & Julius, 2004), ultimately effecting muscle activity. Essentially, L-Menthol application stimulates the TRPM8 ion channel through skin thermoreceptors which depolarises sensory somatic neurons and causes action potentials within the MN's in the muscle. The action potential of MN's in the muscle is caused by the opening of voltage-gated calcium channels which allow the influx of calcium ions between membranes which control the excitability of MN's. The action potential stimulates the motor neuron cell and produces muscle contractions (Voets et al, 2004). Therefore, with the activation of TRPM8 via L-Menthol, this could potentially lead to alterations of neuromuscular activity, by mimicking cool sensation in the body. In addition to the mechanism described above via stimulation of cutaneous afferents via the TRPM8 ion channel. MN's are said to be generally recruited from the smallest to the largest due to size principle (Mendell, 2005). Smaller motor units (MU's) are recruited when less force is needed and when a need for a larger force is required, large MU's are recruited (Milner-Brown, Stein & Yemm, 1973). However, it is stated the order of these MU recruitments can be altered by electrical stimulation of the cutaneous afferents, which inhibits small MU's and excites large MU's (Garnett & Stephens, 1980). This increases the possibility that cutaneous afferent input modulates MN excitability via somatosensory reflex pathways (Tamura, Sugita, Tokunaga, Minegishi & Ota, 2019). It has been reported by Winkel and Jørgensen (1991) SC induced by cold environments enhance muscle activity during repetitive exercise without changes in muscle temperature. Furthermore, a study by Sugawara, Shimose, Tadano and Muro (2012) showed by maintaining the skin temperature around 25°C, using a gel-cooling pad on the quadriceps muscle, it enhanced muscle activity by 15% maximum voluntary contraction (MVC). In comparison, a study conducted by Tokunaga,

Sugawara, Tadano & Muro (2017) showed an application of menthol gel over the working muscles on the skin enhanced muscle activity at a low load (35% MVC). As a result, when comparing the research of SC and L-Menthol on muscle activity, the findings support the mechanism described above, which TRPM8 sensory input is responsible for SC mediated MN excitability (Tamura, 2019).

It is of interest of exercise scientists to explore the capabilities of L-Menthol in exercise performance as it can mimic temperature change of cool sensations (SC) and can alter muscle activity. L-Menthol can induce a potential increase in action-potential due to the ability to mimic a cool sensation. A study conducted by Ricker, Hertel and Stodieck (1977) examined the effects of local cooling on the muscle action potential. Twenty-five subjects were tested. EMG was measured by a steel, active electrode needle and measured muscle activity in the adductor pollicis muscle in the hand. Participants hands were subsequently put into a tank of either cold (local cooling, around 20 ℃) or warm (36℃) water. The nerves of the muscle were then stimulated by two steel needles along the nerve. Ricker and colleagues (1977) found at 36.6℃ the EMG amplitude of the muscle action potential was at 6.6 mV. After local cooling when the muscle was at 18℃, muscle action potential increased to 11.2 mV. This concluded with 24 of the 25 participants experience an increase in the action potential of the muscle when cooled. The authors concluded that the increase of muscle action-potential possibly was caused due to the cooler temperatures on the membrane of the muscle cell. This is also supported by Ludin and Beyele (1997), as they also saw an increase in action potential in the median nerve in the hand after cooling. The studies presently explored, show early indication of how cooling of the skin and muscle can affect muscle action-potential. Therefore, it is interesting to see how L-Menthol may affect action-potential and neuromuscular activity in maximal strength-based activities. Furthermore, over recent years, physiologists have been interested in the topic of understanding the thermoregulatory system and how humans may perceive temperature

change. Therefore, it is suggested the understanding of skin thermal sensations is an important key factor in potentially improving exercise performance (Filingeri, 2011).

2.6 Thermal perceptions

It has been suggested changes in temperature (hot or cold environments) act as a stimulant on the body and it has been shown how these changes in temperature can initiate certain behavioural responses in exercise (Schlader, Stannard & Mündel, 2010). The thermoregulatory behavioural response can be indicated through changes of thermal comfort (TC) and thermal sensation (TS) and is done so by using two subjective perceptual scales of TC and TS (Schlader, Stannard & Mündel, 2010). Both Bleichert, Behling, Scarperi and Scarperi, (1973) and Flouris and Cheung, (2009) studied the effect of TC and TS at rest and exercise. Both studies found with the use of subjective processing of TC and TS, participants tried to behaviourally thermoregulate. The two thermal indices (TC and TS) are fundamentally different; TC can be defined as "subjective indifference with the thermal environment (IUPS Thermal Commission. 2001) and TS aims to identify the "relative intensity of the temperature being sensed" (Schlader, Stannard & Mündel, 2010). Another additional method of thermoregulatory behaviour is voluntary exercise (Mercer & Werner, 2001), for example, voluntary muscular work can retain equilibrium of thermal comfort in cold environments (Caputa, & Cabanac, 1980). Furthermore, it is not essentially the production of heat during exercise that is problematic, but more so the indulgence of metabolic heat that in turn, challenges thermoregulation (temperature) during exercise (Schlader, Simmons, Stannard & Mündel, 2011). Metabolic heat is described as, in tissues, the heat that is generated during a metabolic process in the body, such as growth and energy production of working muscles produces metabolic heat (Singh & Kumar, 2013). In addition, it has been suggested that skin

temperatures are an important mode of signalling and controlling exercise intensity (Jay, 2009). Therefore, when the body exercises and produces metabolic heat, this, in turn, elevates T_{skin} and by using perceptual scales such as TC and TS, this can aid in understanding an individual's thermoregulatory behavioural response to exercise intensity. It is stated, by skin cooling or by using L-Menthol to mimic cool sensations (by not affecting T_{skin}) by triggering TRPM8, which potentially could result in cooler sensations and subsequently increase the intensity of exercise due to improved TC (Montell & Caterina, 2007). TC and TS have been used as means of measurement of thermoregulatory behavioural response in exercise in several studies, with and without the application of L-Menthol.

2.7 Thermal Perceptions and Exercise Performance

Thermal perceptions (TS and TC) have been utilised and been shown to give an insight into thermoregulatory behavioural responses during exercise and may influence exercise performance by exposing the body to warm and cool stimuli. A study conducted by Schlader and colleagues (2011) aimed to explore if T_{skin} played a role in self-selected exercise intensity. The study utilised eight well-trained, male cyclists to complete two 60-minute self-paced cycling sessions as intensely as possible. T_{skin} was manipulated by a liquid conditioning garment (LCG) which participant wore throughout both 60-minute cycling trials. The LCG was either heated from cold to hot (C to H) (-6.3 ± 1.5°C to 61.1 ± 0.6°C) during exercise or cooled from hot to cold (H to C) (61.3 ± 0.5°C to -4.5 ± 1.3°C). Exercise intensity (power output) was measured via cycling cadence, heart rate (HR), mean T_{skin} (measured by skin thermistors), core body temperature, TC (measured on a scale from 1 *comfortable* to 4 *uncomfortable*), TS (measured on a scale from 1 *cold* to 7 *hot*) and RPE were measured at every five- minute interval of exercise. The work completed was recorded by the cycle ergometer output. Their results showed a greater amount of work was completed in the C to H compared to H to C as

the mean power output average was greater in the C to H (258 ± 39 W) compared to H to C (251 ± 35W) (p = <0.01). TC and TS both reflected the changes seen in mean T_{skin}, T_{skin} showed no difference between conditions. However, at the commencement of the exercise, T_{skin} differences showed significant alteration in TC and TS which indicate these thermal perceptions are potential modulators of the exercise intensity (Schlader et al, 2011), established at the start of exercising and driving thermal behaviour (see table 1, values taken from Schlader et al, 2011). This is evident from the average power output and greater work achieved in the C to H condition. The authors concluded that T_{skin} and associated perceptions such as TC and TS are accountable for the initially chosen exercise intensity.

***Table 1**. A table showing the pre-exercise variables of thermal perception and T_{skin} mean (± SD), * Significantly different than C to H (p = <0.05)*

Condition	Tskin (°C)	TC	TS
C to H	29.4 ± 0.9	1.8 ± 0.5	2.9 ± 1.1
H to C	35.2 ± 0.6*	2.7 ± 0.8*	6.3 ± 0.4*

A second study conducted by Schlader and colleagues (2011) investigated temperature and thermal perception as potential controllers of thermoregulatory behaviour in humans. Their study tested twelve physically active male participants in a self-paced cycle at a fixed intensity of 16 of the RPE scale (borg, 1982). The study consisted of five experimental trials which included the conditions; thermal heating, thermal cooling, non-thermal heating, non-thermal cooling and a control (no intervention), which were all applied or directed to the face. Thermal cooling was achieved by forced convection (fan and/or a heater) whilst the non-thermal conditions used sensory compounds such as L-Menthol (cooling) and capsaicin (heated). This study used an 8% L-Menthol gel applied to the entire region of the face for the non-thermal cooling condition. The non-thermal heating condition used a 0.025% concentrated capsaicin

cream. This chemical is said to act upon the TRP ion channel, TRPV1, which is specifically activated upon sensing heat, as capsaicin is an alkaloid found in hot chilli peppers which act upon the same mechanism as L-Menthol does with TRPM8, by depolarising the sensory neurons and facilitates the firing rate of action-potentials which mimics the features of hot sensations (Caterina et al, 1997). During trials, participants wore an LCG. This was to ensure maximal thermal control to ensure no other perceptual effects were experienced. Measurements included; T_{skin}, RPE, Whole body and facial TC and TS (using the same numerical scale as previous in their first study above) HR, total work (kJ) and power output. Schlader and colleagues (2011) observed from their results, the L-Menthol gel significantly (p = <0.05) induced on average, the greater work completed (228.7 ± 23.7 kJ) compared to the control (189.4 ± 16.7 kJ). Furthermore, it is interesting to see the non-thermal and thermal heated conditions were significantly (p = <0.05) different from the thermal cooling condition and L-Menthol condition. The thermal heating condition induced the least amount of work completed followed by the non-thermal heating condition. Both heated conditions saw a significant decrease in the average power output during exercise compared to the L-Menthol condition (p = <0.05). The average facial temperatures were similar in the control and non-thermal heated and cooling conditions (L-Menthol and capsaicin, p = >0.05), however, the thermal heat and cooling conditions expressed significantly different facial temperatures (i.e. cooler in the thermal cooling and warmer in the thermal heating, p =<0.001). both heating conditions were significantly different compared to the cooling conditions in both TS and TC of the face during the whole exercise. Therefore, participants felt significantly cooler and comfortable in the cooling conditions. This was the same for TS whole body, however, TC whole body was less modulated but still showed specific significant differences in perception at specific percentages of work completed. Thermal cooling showed significance in TC whole body compared to both heating conditions (more comfortable), however, L-Menthol gel showed at 40 and 60% of

exercise completion, participants felt significantly more comfortable. The results of this study evidentially show that 8% L-Menthol gel repressed warmth perceptions and most interestingly, L-Menthol gel clearly improved whole-body thermal sensation perception making participants feel cooler and partly whole-body TC without observing any significant reductions in the average T_{skin}. In addition, it shows that L-Menthol can elicit the same responses in exercise, similar to the responses seen when only thermal cooling is applied.

Studies, as described above which show potential improvement in exercise performance, give a foundation of the possibility of how L-Menthol could be used to enhance thermal perceptions and induce greater exercise performance due to its ability to mimic cool sensations and without notably changing T_{skin} potentially due to the TRPM8 mechanism. Gillis and colleagues (2010) also saw significant changes in TS whilst using a 0.20% and 0.05% concentrated L-Menthol spray which made participants feel cooler compared to a non-L-Menthol spray without seeing any significant changes in T_{skin}. Similarly, A study conducted by Bright, Chaseling, Jay and Morris (2019) observed that participants perceived their thermal sensation (whole-body) (TS_{wb}) to be significantly cooler in the L-Menthol neck cooling trial (p = <0.013). By exploring L-Menthols ability to induce cooler sensations (TS) and increase comfort (TC) like-wise from the study conducted by Schlader and colleagues (2011), this could make L-Menthol an important tool in other activities where TS and TC may limit performance, such as strength-based activities. However, thermal perceptions are not the only variable which can be measured to understand exercise intensity. RPE is a widely used perceptual measure, which has been used in several studies to investigate thermoregulatory behavioural responses during exercise (Tucker, Marle, Lambert & Noakes, 2006).

2.8 Rating of Perceived Exertion

It is established thermal perceptions (TS and TC) govern how the body reacts and responds to different environments (hot/cold) during exercise (Schlader, Simmons, Stannard & Mündel, 2011). Alternatively, previous literature suggests the perception of effort (exertion) can moderate thermoregulatory behaviour and regulate self-exercise work rate (Tucker et al, 2006). RPE is primarily a combination of signals received by the CNS and PNS into one indicator of perceived physical strain; the Borg scale is used as a subjective scale to measure rating of perceived exertion which ranges between 6-20, 6 being no exertion at all and 20 being maximal exertion (Borg, 1982). A study conducted by Crewe, Tucker and Noakes (2008) studied the effect of the rate of increase in RPE in different environmental conditions. Seven well-trained cyclists were used to perform five fixed intensity cycling trials in five different environmental conditions. Two trials performed in 15 °C at 65 (C65) and 70% (C70) peak power output (PPO) and three trials in 35 °C at 55 (H55), 60 (H60) and 65% (H65) PPO. RPE was measured along with T_{skin} and rectal temperature. The results from this study firstly exhibited RPE increases linearly alongside fixed exercise intensities which have been previously seen in cycling exercises (Garcin et al, 1998; Garcin & Billat, 2001; Nethery, 2002). The second key finding of this study was time to exhaustion was inversely associated with the rate of RPE increase. When comparing the exercise duration to fatigue and RPE of each condition, it was evident the rate of increase in RPE of the subjects became a predictor of the total duration of the exercise. Briefly, H65 and C70 both had the shortest duration and saw the fastest increase of RPE compared to the other conditions and was significantly different to H55 and C65 which had the longest time to exhaustion (p = <0.05). This was evident from the result of the duration of the fixed exercise intensity and ambient temperatures experienced. Crewe and colleagues (2008) concluded since the rate of increased RPE was set from an earlier stage in trial H65 and C70, it indicated that the brain via the CNS and PNS (i.e. skin thermoreceptors) sensed the increased

exercise intensity and hotter conditions. Further supporting evidence of this notion was the significant difference between H65 and C65 of the exercise duration and rate of increase of RPE which verifies endurance exercise performance is negatively affected by hot environmental temperatures. More so, the variance of environmental temperature is sensed in the early stages, via the skin thermoreceptors as core body temperature change so early on in exercise is improbable, which is supported by Tucker and colleagues (2004). Rectal temperature was significantly correlated with RPE (p = <0.05) and increased linearly, however, this association has been seen previously at fixed intensity rates (Nielsen et al, 2001 and Nybo & Nielsen, 2001). RPE can be considered as a key element of exercise performance possibly contributing to thermal perception using afferent feedback through skin temperature and heat storage via metabolic rate. In the next section of the present literature review, RPE will be investigated with the application of L-Menthol.

2.9 The Effect of L-Menthol on Exercise Performance and the Applications of L-Menthol

Studies have explored ambient temperatures and L-Menthol and their effects on thermal perceptions, perceived exertion and the potential of altering muscle activity. With L-Menthol's ability to mimic cool sensations, and the practical benefits L-Menthol may allow (i.e. a more ecologically valid modality of enhancing performance compared to thermal cooling intervention which is not achievable when exercising), this has become a focal point for exercise physiologists to explore the effects of L-Menthol further on exercise performance which may take place in hot and humid climates As it is reviewed above, hot ambient environments cause detrimental effects on exercise performance. Many sporting events and competitions are held in other countries which can be often hot and humid, where ambient temperatures can rise and maintain up to >30 °C (Stevens, 2017). For example, events such as; The Tour de France cycling race which is held over three weeks, marathons des Sables and

future events; Olympics 2020 in Tokyo (which offer a variety of exercises, from endurance to strength and power-based activities) and the Fifa world cup in 2022 held in Qatar all endure hot and humid environments (Flood, 2018). It is stated, core body temperatures that exceed 40 °C from exercise fatigue are said to lead to heat-related illnesses (Bongers et al, 2015). Previous evidence suggests by decreasing or stopping the body's core temperature to reach critical levels improve exercise performance and therefore, practical cooling strategies to cool down the body have been explored to relieve the body of heat stress and limit the attainment of critical core temperature (Jones et al, 2012). In addition, the level of fatigue seems to be enhanced due to increased feelings of thermal discomfort (i.e. feeling hot and uncomfortable) which may be an influencer for early onset of fatigue (Barwood et al, 2015). A few different modes of application of L-Menthol have been utilised and mentioned in the present literature review such as L-Menthol sprays and gels. However, not all modes of using L-Menthol have been mentioned.

There are different methods of using L-Menthol to combat thermal discomfort in hot and humid environments and to reduce the onset of fatigue, which consist of internal and external methods of use (Flood, 2018). The internal method of use of L-Menthol consists of swilling/rinsing with L-Menthol, which has been performed by Best, Spears, Hurst and Berger (2018); Stevens (2016) and Mündel and Jones (2010) adopting a mouth swilling L-Menthol solution in their studies. An external method consists of a spray or gel application applied to the skin (Flood, 2018). By using L-Menthol has an internal or external intervention, L-Menthol can aim to improve thermal and exercise perceptions (Mündel & Jones, 2010). Thermal perceptions of temperature input can be measured by using TC and TS scales (Stevens, Mauger, Hassmen & Taylor, 2018). It is stated by Stevens and colleagues (2018) that L-Menthol permits the separation of perception and thermal state (core temperature). Therefore L-Menthol could be beneficial to elite athletes exercising in hot environments to perceive lower thermal perceptions without having to perform thermal interventions, such as; whole-body cold water immersion,

ice jackets or part cold water immersion indicated by elevated skin temperature or thermal perceptions (Bongers et al, 2015). L-Menthol has also been applied to clothing i.e. soaking garments in L-Menthol as an external method of application (Gillis, 2016).

Over recent years there have been several studies which have researched the effects of L-Menthol on exercise performance, primarily endurance based and in hot and humid environments. A study conducted by Barwood and colleagues (2014) examined six untrained male participants across three experimental trials of endurance exercise in hot conditions (34 °C) inside an environmentally controlled chamber. Their clothing was sprayed with either a control-spray, an L-Menthol spray or was not sprayed at all. Participants completed a fixed intensity period for 15 minutes. Participants clothing were then sprayed with 100mL of the solution containing 0.20% L-Menthol, or the control-spray and then asked to complete a 5 km treadmill TT. Thermal perceptions (TC and TS) were recorded along with RPE at 1 km. TT duration was recorded at every 250m split. T_{skin} and the aural temperature was measured. Interestingly, Barwood and colleagues (2014) found no significant difference between TC and TS at the end of the fixed intensity exercise period and word descriptors equated to "warm to hot" (TS) and "just uncomfortable" (TC). Interestingly, following the application of the spray during the 5km TT, TS was significant between conditions (p = .002) and an interaction effect (p = .006). TS votes in the L-Menthol condition were significantly lower (feeling cooler) compared to the control (p = .007) and the control-spray (p = .002). The effect of the L-Menthol spray sustained as the TT continued up to the 3 km mark but not beyond 4 km and 5 km. There was no difference in RPE between conditions, or skin and aural temperature. The conclusion made from these findings is, the L-Menthol spray gave no ergogenic effect to high-intensity endurance performance. Although, L-Menthol did change the TS perception of participants without seeing any reductions in T_{skin}. However, it is noteworthy that it was evident that the effects of 0.20 % L-Menthol spray decayed between the region of 19 (3km) and 24 (4km)

minutes. This corresponds with the findings of Gillis and colleagues (2010) who suggested 20 minutes of L-Menthol stimulation, may require L-Menthol reapplication to induce any beneficial ergogenic effect. The results of Gillis and colleagues (2010) correspond closely to the findings of Barwood and colleagues (2014) which explored similarly endurance exercise in hot conditions. They found comparable results with TS and TC. Gillis and colleagues (2010) found no significant differences in TC between conditions but reported significant differences between conditions of TS ($p = 0.001$). This study was performed with the application of soaking garments with L-Menthol.

A recent study conducted by Barwood and colleagues (2019) studied the effects of repeated L-Menthol spray application in hot environmental conditions via a set 35°C chamber on eight trained cyclists. Subjects completed two separate conditions which included a 45-minute fixed intensity cycle followed by a time trial to exhaustion (TTE). One hundred millilitres of 0.20% L-Menthol spray or a control spray was applied to the subject's T-shirt at 20 and 40 minutes of exercise. thermal perceptions: TC and TS were measured along with RPE, TTE duration, skin and rectal temperature. Perceptual measurements were measured at every 10-minute interval before the first spray (20minutes) and then collected following every 5-minute interval. The results showed a significant difference in TTE ($p = 0.004$) between conditions in which subjects performed much longer with the L-Menthol spray application. TS were similar prior spraying (20minutes) equating to the word descriptor "hot" in which 5-minutes after spraying with the L-Menthol was significantly lower showing a main condition effect ($p = 0.008$) and interaction effect ($p = 0.001$), similarly to the previously outlined above, this difference was seen compared with the control condition ("cold" and "warm to hot") respectively. However, the effects of L-Menthol spraying sustained up until 40-minutes where TS was not different ($p = .255$). With the second application of L-Menthol spray, 5-minutes after, TS declined again ($p = .035$). TC only changed in numerical value, i.e. the TS and TC scales as previously

mentioned measured across a 20 cm line (see appendix *E*). Subjects felt more comfortable with the L-Menthol spray than the control spray, however, it was not statistically different. RPE did not differ. The rectal temperature increased steadily throughout, indicating heat was being produced (main time effect $p = .001$), but no interaction or main condition effect. There was no significance in T_{skin}, however, numerically was decreasing following the pattern of TS. This study is one of the first studies that showed L-Menthol spray improved TTE performance and became an ergogenic aid during cycling in hot conditions, however, repeated L-Menthol spraying did not provide a greater benefit to thermal perceptions as only TS was significant.

In relation to the study of Barwood and colleagues (2019), only one other study has proven L-Menthol application to be ergogenic and this was the study previously described by Schlader, Simmons, Stannard and Mündel (2011) which tested the 8% L-Menthol gel on the face. The results from this study saw an 18% increase in total work in the L-Menthol application condition and shorter exercise durations were observed in the heated conditions, particularly in the capsaicin application condition (Schlader et al, 2011). It is worth mentioning that with studies which have used an ecologically valid approach, L-Menthol as an ergogenic aid is elusive on improving exercise performance and thermal perception is the primary component it affects (Stevens & Best, 2017; Barwood et al, 2019). Collectively these studies show that the topical application of L-Menthol on improving performance should be further investigated in other areas of exercise, such as strength and power-based exercise and not only endurance-based exercise, as there is clear evidence that the mechanisms of which L-Menthol act upon (i.e. TRPM8, PNS and CNS) can evoke potential improvements in exercise without having to perform non-ecologically valid interventions. There is also evidence of L-Menthol's potential ability to evoke greater power outputs and that there may be a potential effect on peripheral muscular facilitation, which was mentioned as part of the mechanism of activating TRPM8 ion channel, previously mentioned in the present review.

2.10. Electromyography and Muscle Activity

Electromyography has been briefly mentioned above in the present literature review, used as a measurement of neuromuscular activity in exercising muscles. EMG has been for many years, an attractive model to evaluate muscle activity and fatigue (Petrofsky & Lind, 1980) and it is stated by previous literature, muscle performance is influenced by temperature, like most biological processes (Bennett, 1985). The electrical neuromuscular signals (activity) of an exercising muscle is shown by surface EMG (Blake & Wakeling, 2013). However, the surface EMG of muscle activity and the relationship with temperature has not been well studied (Quesada et al, 2015). A study conducted by Abbiss and colleagues (2010) examined the effects between hot and cold environmental temperatures on muscle activation, body temperature and perceived exertion on nine endurance-trained cyclists performing three self-paced cycling trials of 100km. Trials were performed in a climate chamber, one at neutral temperature (22.3 °C), hot (33.7 °C) and cold (10.5 °C). The results showed performance time in the hot condition was slower compared with the cold condition (p = <0.001), power output decreased in the hot compared to cold condition and EMG of the bicep femoris and soleus was significantly lower in the hot than the cold condition (p = 0.003 and p = 0.001), whereas the vastus lateralis EMG was not different between conditions. The authors concluded environmental temperatures may influence performance in dynamic endurance exercise, through evidence of the decrease in muscle activation and of power output in the hot environment in contrast with the cold environment. In addition, due to the decrease in muscle activation, this led to the decline of power output able to be produced to ultimately stop the reach of critical body temperatures (39.5 – 40.5 °C) (Abbiss et al, 2010). This is supported by the findings of Tucker and colleagues (2004), which showed EMG amplitude was lower in hot than cool environments during endurance exercise. It is becoming evident exercising in a cold environment does not cause thermoregulatory strain to become performance-limiting.

With evidence suggesting hot environmental temperatures are detrimental than cold temperatures on muscle activity/activation and endurance performance, it is said the RFD can provide integral evidence of neuromuscular function which is echoed by increasing surface EMG activity (Girard & Millet, 2009). Furthermore, it is stated RFD is a key component to be able to perform rapid and forceful movements (Aagaard, 2003). A study conducted by Holtermann, Roeleveld, Engstrøm and Sand (2007) studied the effect of resistance training on RFD and reported an association with the excitability of MN's with an increased RFD. Therefore, increasing the excitability of MN's could theoretically improve RFD. In relation to MN's, it is specified, an input to the skin can alter motor unit recruitment threshold (Masakado, Kamen & De Luca, 1991). Several studies have explored the idea of SC and its effects on MN excitability. The neuromuscular alteration could be changed by thermal inputs from cold environments which limits the alteration of muscle temperature and improves muscle activity (Yona, 1997; Winkel & Jørgensen, 1991 and Rissanen, Oksa, Rintamäki & Tokura, 1996).

One study conducted by Shimose and colleagues (2014) examined the effects of SC on RFD in the quadricep muscle during isometric maximal contractions loaded at 35%. The maximal quadricep muscle strength was measured using a maximal isometric knee extension exercise in the participant's dominant leg. Surface EMG was measured at the vastus medialis, rectus femoris and vastus lateralis. SC was achieved employing a gel pack which was attached and applied around the quadricep and cooled. The gel pack was cooled to the point the muscle could attain a 25 °C temperature. This was compared with a control which used a non-cooled gel pack. Muscle temperature was measured using a wire type thermistor. The key finding from the results of this study was the increase of rmsEMG and RFD in the SC condition compared to the non-SC condition. SC of the working muscle facilitated the increase of neural drive (represented by rmsEMG) and increased RFD compared to the non-SC, with a correlated increase of surface EMG activity in the early phases of maximal isometric contractions (0-30

and 0-50 ms) (SC: 937.8 ± 468.7, 1077.5 ± 532.8 and non-SC: 791.8 ± 369.3, 938.1 ± 444.7 N. s^{-1}, p = <0.05), respectively. To clarify, the rmsEMG is interrelated with an amplitude of surface EMG which signifies the overall MU recruitment (Farina, Merletti & Enoka, 2004). Thus, an increase in rmsEMG elicits an increase in the number of MU's recruited. In conclusion, this study suggests that SC increases RFD by a collaboration of PNS via thermoreceptors, particularly cold receptors of the skin (Shimose et al, 2014). This is a plausible but unexplored mechanism by which an L-Menthol application could affect dynamic and static muscular movements. The plausible mechanism suggested by Shimose and colleagues (2014) relates to the mechanism described earlier in the literature review. As shown, SC has potentially stimulated cutaneous afferents through the sensory somatic nervous system and has activated the highly sensitive TRPM8 ion channel. The sensory information which has been transmitted to the CNS generates electrical signals. This generates rapid influx of action potential through the MN due to activation of the TRPM8 ion channel, and exciting the MU's within the muscle, allowing more force to be generated, which results in an increase in surface EMG and rmsEMG.

2.11. L-Menthol and Strength Performance

There is a huge emphasis on using L-Menthol application in endurance activities in previous literature to improve thermal perceptions, RPE and its ability to be an ergogenic aid for endurance performance in the heat, due to its ability to mimic cool sensations. However, there is extremely limited research using L-Menthol as an ergogenic aid for strength performance and how L-Menthol acts upon maximal and sub-maximal muscle strength and power. The relationship between muscle activation and the temperature has briefly been researched and has been previously explored, as Abbiss and colleagues (2010) studied the combination of alternate environmental temperatures and muscle activity in endurance cyclists and saw decreases in EMG activity in the hot conditions. This was similar to the findings of Tucker and

colleagues (2004). Shimose and colleagues (2014) then studied the effect on skin cooling via a cooled gel pack and maximal isometric knee extension at a 35% load. The author's conclusion was skin cooling improved the rate of force developed. With this said, the effect of L-Menthol on neuromuscular activation has yet to be investigated (Huffman et al, 2010). The only study to our knowledge which has tested the effects of L-Menthol on neuromuscular changes was by Tokunaga, Sugawara, Tadano and Muro (2017).

Tokunaga and colleagues (2017) examined the neuromuscular changes that occur after a 5% L-Menthol gel was applied to the skin during 35% MVC of the quadricep during muscle contraction. The study recruited forty-two healthy adults ranging between 20-65 years split into three groups: adult placebo, adult L-Menthol, and older adult L-Menthol. Surface EMG was used to measure the quadricep muscle at the vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF). The results of the rmsEMG in the VL and VM saw a significant interaction effect between conditions and groups (p = <0.01) and a main condition effect in test conditions of all three muscles (p = <0.01 for VL and VM; p = <0.05 for RF). The rmsEMG differences showed a significant increase with the L-Menthol application compared to the control (p = <0.01). Mean power frequency (MPF) was also statistically analysed showing a significant interaction effect of the VL (p = <0.05) and a main condition effect in the VM and RF (both; p = <0.01). These differences in MPF were significant in the older adult L-Menthol condition, however not significant in the adult L-Menthol condition. What can be taken from these results is rmsEMG in the VL and VM significantly increased with L-Menthol stimulation in both adult and older adult and a significant decrease was observed in MPF in the VM in older adults but not adult L-Menthol. Therefore, it can be concluded from this, neuromuscular modulation was shown with the application of an L-Menthol stimulant (gel) at a low load of MVC's.

2.12. The Unexplored Research Gap

The study conducted by Tokunaga and colleagues (2017) was to our knowledge the first of its kind. Although the study was originally aged focused, it can relate to a degree, to sport and exercise performance, by using L-Menthol gel to enhance low load contractions. L-Menthol application has primarily been used for endurance exercise in hot ambient environments (Barwood et al, 2012; Barwood et al, 2014; Gillis et al, 2010 & Barwood et al, 2019) due to L-Menthol's ability to mimic cool sensations via afferent skin thermoreceptors activating TRPM8 ion channel. It has been described above how L-Menthol application can affect thermal sensations, fatigue, and exercise performance and how temperature can influence muscle activation via excitability of MN's and recruitment of MU's. A common theme amongst the L-Menthol literature has been the growing question of whether L-Menthol can be used as an ergogenic aid in exercise endurance performance in hot ambient environments. Barwood and colleagues (2019) saw that topical L-Menthol application was performance-enhancing despite previous studies where L-Menthol application was not seen to be ergogenic and concluded that it is conceivable that topical L-Menthol application could be ergogenic in other exercise activities, such as strength and power-based activities (Barwood et al, 2019). In regards to the study conducted by Barwood and colleagues (2019), other previous studies have researched concentrations of 0.05% and 0.20% of topical L-Menthol application and the evidence suggests 0.05% and 0.20% can affect thermo-perception and do not cause any harm to thermoregulation. However, the most recent work by Barwood and colleagues (2019) used a topical application of L-menthol at a concentration of 0.20%. This showed performance benefits using a topical L-Menthol application of 0.20% and affected thermo-perceptions. This provided the rationale for the concentration used in the present study.

This leads to a clear gap in the literature on the effect of L-Menthol application on strength and power-based activities. Accordingly, the purpose of this study was to evaluate maximal dynamic and static resistance exercise performance using the deadlift exercise and the isometric mid-thigh pull manoeuvre. Strength can be defined as a "fundamental quality necessary in achieving optimal physical function and the ability to produce more force" (Siff, 2000; Juneja, Verma & Khanna, 2012) which can be measured dynamically and isometrically (Stone, Moir, Glaister & Sanders, 2002). The deadlift is considered to be one of the best dynamic exercises for whole-body strength and is one of the main three exercises that are used in power-based competitions (Beckham et al, 2012; Gotshalk, 1984). The Isometric mid-thigh pull (IMTP) is a specific position used in weightlifting to assess for peak forces of athletes, and it has been examined to show high levels of peak force (Haff et al, 1997; Juneja, Verma & Khanna, 2012). With that being said, in dynamic activities such as weightlifting, it is suggested it is reliant upon peak forces (Garhammer, 1993; McBride et al, 1999). The use of isometric assessment for muscle function has been used for many years (Wilson & Murphy, 1996). Furthermore, isometric tests are easily executed as they primarily consist of a singular maximal contraction with moderately simple and easy to use equipment (Juneja, Verma & Khanna, 2012). In addition, the IMPT is time efficient, considered safer than performing dynamic 1 repetition maximum (1RM) testing and induces minimal fatigue (Dos' Santos et al, 2018). Several studies have used the IMTP as a measure of isometric strength using multiple muscles in a group action (Stone et al, 2003; Stone et al, 2004; McGuigan, Winchester & Erickson, 2006; Mcguigan, Newton, Winchester & Nelson, 2010; Kraska et al, 2009; McGuigan & Winchester, 2008). In addition, the IMTP has been shown to be highly reliable both within and between sessions, with low variability and low measurement error (Comfort et al, 2019). Previous studies have shown reliability coefficient of 0.89 and a reliability of 0.819 between sessions, (Comfort, Jones, McMahon & Newton, 2015; De Witt et al, 2018) respectively, which

indicates reliability of the IMTP is very reliable. Furthermore, it is suggested maximal strength is seen as a major contributing variable that overall influences a variety of sports, particularly sports involving high force production and high-power outputs (Stone et al, 2002; Stone et al, 2005). This has been shown in a study which explored the importance of isometric maximum strength in college wrestlers, which McGuigan and colleagues (2006) saw that the isometric mid-thigh pull test is related strongly with 1RM. However, regarding achieving high levels of maximum strength, the limitation of achieving greater maximum strength is strongly related to the ability to be able to produce increased peak power and greater RFD from the exercising muscles, especially for weightlifting success (Stone et al, 2005). In relation to L-Menthol and the limited research conducted on muscular strength, it has only been seen by Tokunaga and colleagues (2017) that rmsEMG was significantly increased by L-Menthol gel on low load contractions, which has been shown in the above review to be linked with increased RFD which in turn is associated with increased MN excitability and recruitment. Therefore, the ability to produce greater peak power and greater RFD is a key limitation on being able to achieve an increase in maximal strength performance. Theoretically, L-Menthol application could potentially be used as an ergogenic aid to enhance maximum strength performance.

To summarise, the effects of L-Menthol application have not been examined on maximal dynamic and static exercise resistance performance. It has been suggested by recent literature (Barwood et al, 2019) that this should be further studied as it may have potential ergogenic effects in strength and power-based activities. There is a plausible mechanism by which L-Menthol, as described in the above literature review, could benefit dynamic exercises such as the deadlift and maximal isometric strength by using the IMTP manoeuvre. By presenting a study in this topic would make it the first of its kind, highly unique and of interest to sporting literature.

2.13. Aims and Hypotheses

This study will aim to examine the effect of a single low concentration L-Menthol application of 0.20% to the skin on explosive maximal, dynamic, and static resistance exercise performance. This will be compared to a control-spray condition. The study will test the following null (H_0) and experimental (H_1 and H_2) hypothesis. The Hypotheses for the L-Menthol application include:

H_0: Sprayed L-Menthol application to the legs prior to maximal and sub-maximal resistance exercise will not alter weightlifting performance.

H_1: Sprayed L-Menthol application to the legs prior to maximal and sub-maximal resistance exercise will improve weightlifting performance by enabling participants to lift more weight and will lower perceived exertion.

H_2: Sprayed L-Menthol application to the legs prior to maximal and sub-maximal resistance exercise will improve lifting performance by enabling participants to lift more weight and alter muscle electromyography (EMG) activity indicating peripheral muscular facilitation.

Chapter 3

3. Chapter Overview

The primary aim of this section is to produce data which will test the hypothesis stated above using a reproducible method that is sufficiently detailed to repeat from section reading.

3.1 Experimental Design

Ethical approval was granted by the Leeds Trinity University School of Health and Social Sciences ethics committee in advance of the study (code: SHSS-2018-049). The study utilised was a within-participant repeated measures design with each participant acting as their own control. The main experimental trials were randomised using a commercially available randomisation tool (website: https://www.sealedenvelope.com/simple-randomiser/v1/lists, on 9th April 2019 at 21:00, unique ID: 276991048306206) and double-blinded. This type of design was used to reduce any possible bias towards producing experimental effects by social facilitation through inadequate blinding (Triplett, 1898). The primary Independent variables of this study relating to the hypothesis included: The L-Menthol treatment. The Dependant variables include RPE, TC, TS, number of repetitions, the force produced (weight pulled) and surface electromyography (EMG). The remaining variables were included for exploratory purposes.

This sample size was calculated on the magnitude of performance effect seen in the recent study by Barwood and colleagues (2019); GPower, version 3.1, University of Dusseldorf, Germany; difference between conditions 133 seconds, SD 104 seconds; effect size 1.27; power 0.95. The result of this calculation indicated nine participants would be required although twelve participants were recruited to allow for participant attrition. Previous similar studies have shown significant differences in similar experimental designs with ten participants or less (Jeffries et al, 2018).

Briefly, participants attended the Leeds Trinity University Strength and Conditioning suite (S and C) on three separate occasions, one visit per week, for a total of three weeks (see figure 1). These visits comprised of one baseline, one control-spray and one L-Menthol spray condition. Each baseline test lasted approximately 90 minutes and the experimental treatment condition visits lasted approximately 60 minutes. The first visit established each participant's baseline performance levels with maximal and sub-maximal lifting (deadlift exercise) to firstly, predict maximal lifting capability and secondly, prescribe a lifting intensity for visits 2 and 3 (intervention conditions). Each participant completed a second and third visit, which consisted of either a control spray or an L-Menthol spray being applied to participants legs prior to resistance exercise. Participants were asked on each occasion before each visit to abstain from heavy, strenuous exercise and alcohol consumption 24 hours prior to testing and no caffeine consumption at least 8 hours prior to testing. All trials took place at the same time of day to minimise circadian effects (+/- 1-hour difference). This was controlled as closely as possible.

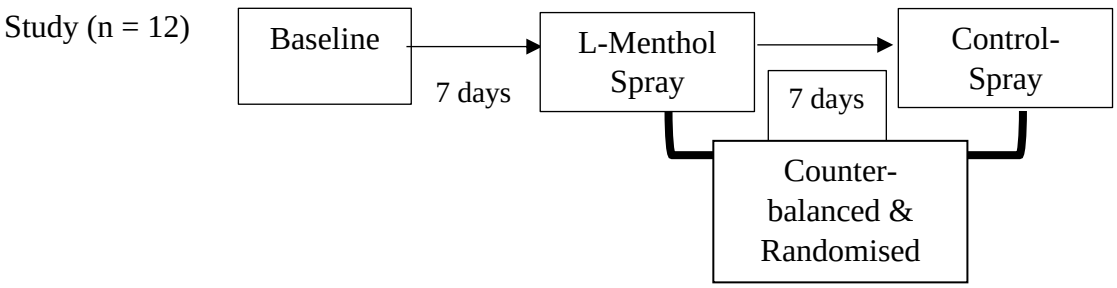

Figure 1*. The order of test conditions during the study; each box represents one visit.*

3.2 Participants Characteristics

Twelve healthy, physically active male participants mean (±SD), aged 24 ± 4 years, body mass: 75 ± 8 kg, height 173 ± 7 cm, volunteered for this study. The inclusion criteria were males only, between the ages of 18 and 40 years and accustomed to maximal lifting and resistance training exercise. All participants required and had at least 12 months prior maximal weightlifting experience and were resistance-trained (i.e. they took part in resistance training

exercise three times per week). Participants were excluded if they had any existing cardiovascular, musculoskeletal injury or any contradictions that could have been exacerbated by completing the study as indicated by their answers to the physical activity readiness questionnaire screening (PAR-Q) (see appendix A). Further exclusion criteria included, participants reporting any allergies towards L-Menthol (amongst an extended list of ingredients - chemical Associates, Rosemead, Frodsham, United Kingdom) or any of the other constituents of the sprays.

Each participant was blood pressure screened using a digital automatic blood pressure monitor (OMRON, MX2 Basic, Japan) and had a mean (±SD) systolic pressure of 133 ± 8 mmHg and a diastolic pressure of 66 ± 10 mmHg. Participants were excluded if their systolic blood pressure was $\geq$145 mmHg and diastolic of $\geq$90 mmHg as this was considered as a hypertensive risk. One participant was recruited and excluded due to their blood pressure being above the stated values and was advised to contact their GP. Participants were all given a participant information sheet (see appendix B) to read and provide a basis to ask any questions about the study prior to arrival to the first visit. The information sheet outlined the potential primary risks and procedures. Once the participant was content with the information, completed the health screening and was verified as having no underlying medical concerns, the participant signed a consent form (see appendix C). Participants were free to withdraw from the study and were informed of the withdrawal procedure in the participant information sheet (see appendix B). This states that they were free to withdraw for up to 14 days after data collection was complete by contacting the project supervisor. No participants withdrew from the study. This study was conducted in accordance with Leeds Trinity University and its safety regulations and risk assessment procedures.

3.3 Experimental Procedures

3.3.1 Preparatory Procedures

Prior to each visit, participants were reminded to bring suitable sports clothing, such as a comfortable lightweight T-shirt, comfortable, non-tight shorts, and shoes (comfortable with arch support) for weightlifting purposes. Participants were asked what their 5 repetition maximum (5RM) of a deadlift based on their prior lifting performances and experiences with a hexagonal bar. A hexagonal bar was used to minimise potential interferences with wired measurement systems (see figure 2).

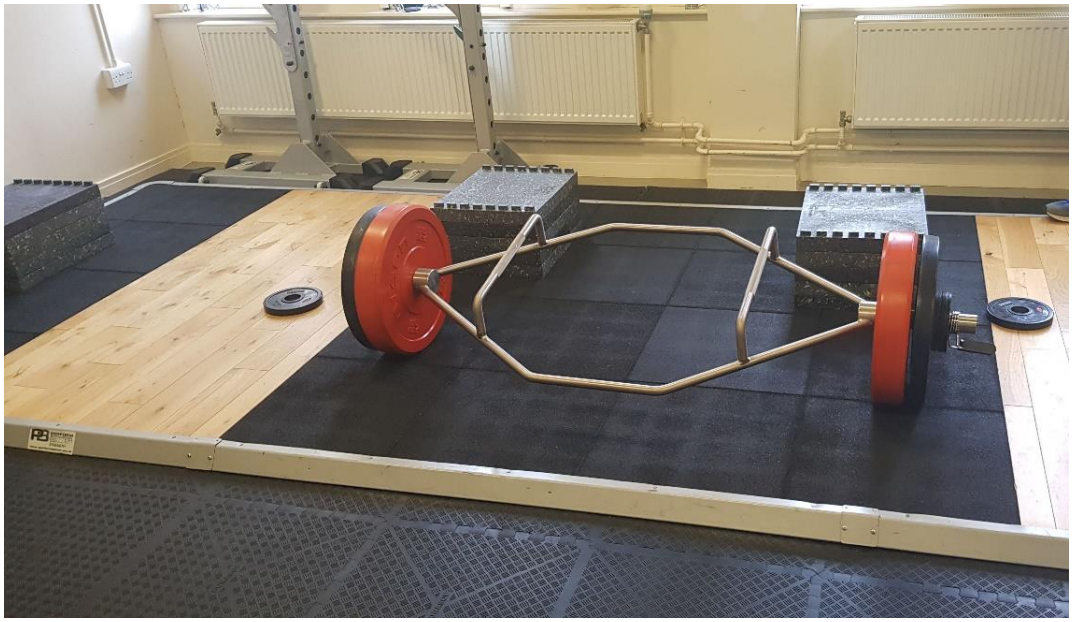

***Figure 2**. An image showing the hexagonal bar used to perform the deadlift manoeuvre.*

This was needed as a baseline estimate to start the 5RM protocol (Reynolds, Gordan & Robergs, 2006). The participant was asked to read a descriptive, visual layout of events in chronological order and to listen as the baseline visit was explained. Once the test was explained, the participant was asked to put on a HR monitor and strap (FT1, Polar Electro Oy, Kempele, Finland) and complete a standardised warm-up (WU) of 5-minutes sub-maximal cycling on a static exercise bike (Monark 818 static bike, Vansbro, Sweden) at a fixed intensity of 150 Watts and a cadence of 70 revolutions per minute. During the WU, the humidity and

ambient temperature values were noted and were manually recorded by a CM9088 Temperature and Humidity Forecast Station (ClimeMET, China) on every visit. Before the sub-maximal WU, measurements, such as the rating of perceived scale (RPE) and Readiness to Train scale (RTT) (see appendix D) were explained to the participant using a standardised set of instructions. Participants reported their RTT and RPE at set intervals throughout visits one to three (see figure 3 for measurement intervals). After the prescribed WU on the cycle ergometer, the participant was free to complete self-directed static and dynamic stretching of the major muscle groups involved in the weightlifting before starting the specific warm-up (SWU). Participants were then instrumented with EMG electrodes (sensors) (Delsys, Trigno, Delsys, USA) at three different anatomical locations; Rectus Femoris (RF), Bicep Femoris (BF) and the medial gastrocnemius (MG).

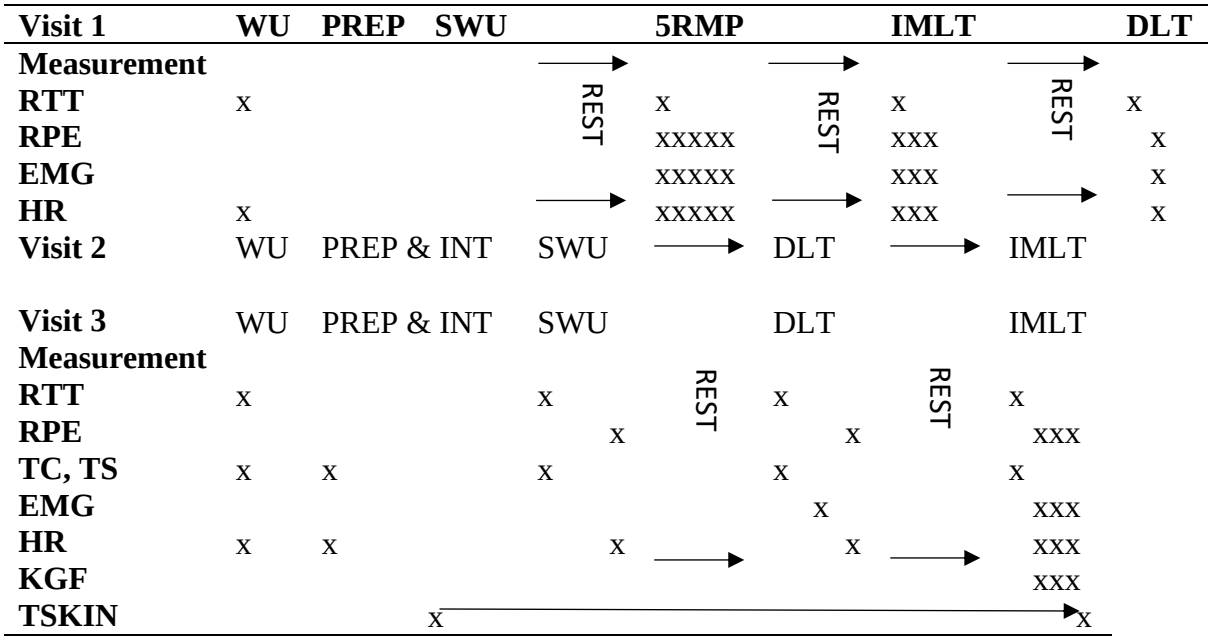

Figure 3. *Visual representation of study design and frequency of measurements. List of design abbreviations: warm-up (WU), preparation period including instrumentation (PREP), specific warm-up (SWU), five repetition max protocol (5RMP), isometric maximal lifting task (IMLT), dynamic lifting task (DLT), the intervention of control or L-Menthol spray application (INT). Measure abbreviations: readiness to train (RTT), rating of perceived exertion (RPE), thermal comfort (TC), thermal sensation (TS), surface electromyography (EMG), heart rate (HR), Kilogram weight pulled (Kgf), skin temperature (T_{skin}); x indicates discrete measurement point, the arrow indicates continuous measurement, Black vertical lines indicate start and end points of measurement frequencies. Arrows above and below "Rest" indicates duration of rest.*

3.4 Baseline Test - Visit One

The baseline test consisted of three tasks: an estimation of 1RM (using 5RM protocol), Isometric Maximal lifting task (IMLT) and a familiarisation task. The estimation of 1RM consisted of five sets of five repetitions (5RM protocol). The IMLT consisted of three repetitions held for three seconds and each repetition was separated by 90 seconds of standing rest in between and the familiarisation involved one set of five repetitions of 75% of the calculated 1RM from participants final 5RM from the 5RM protocol (Reynolds et al, 2006). Participants were asked to be seated whilst Electromyography electrodes were applied to the RF, BF, and the MG on the participant's dominant leg. Locations of the electrodes on each muscle were marked clearly and maintained using a marker pen system. During instrumentation, participants were shown a brief video clip of a Hexagonal bar deadlift manoeuvre using the correct form and continuous movement required from the participants. The qualified trainer provided initial technique guidance on movement efficiency (a qualified S and C trainer attended each baseline test). Once the electrode instrumentation was complete, the trainer and lead researcher loaded the hexagonal bar to 50% of the participants' self-predicted 5RM. This percentage was used as a sub-maximal weight, which participant used to perform a SWU of the deadlift manoeuvre.

3.4.1 Estimation of 1RM

Participants performed an estimation of their 1RM using a 5RM protocol (Reynolds et al, 2006) (see figure 4). A protocol that allows 1RM to be predicted by establishing the actual 5RM of the participant (Reynolds et al, 2006). This was implemented due to Leeds Trinity University do not allow direct testing of 1RM due to their risk assessments. Establishing the 1RM is

extremely important as it determined the target weight for visits two and three to be lifted. The 5RM protocol consisted of five repetitions for five sets (Reynolds et al, 2006). Before the 5RM protocol began, participants performed a SWU. The weight was loaded to 50% of the reported 5RM and the participant was asked to stand in the middle of the hexagonal bar and obtain the correct form before lifting. Once the trainer was content with the participants starting lifting position, the participant was asked to begin the SWU and performed five continuous repetitions. No EMG data were recorded during the SWU. Participants were asked to wait precisely three minutes before performing the second set of five repetitions. HR was noted following 30 seconds after the second set of five repetitions of the SWU. Once complete, the participant was asked to step outside of the bar and rest for three minutes. The bar was loaded to 75% of the participants reported 5RM. Once the three minutes had passed, the participant was asked to give a perceptual rating of their RTT pre estimation of 1RM. Participants were asked to follow a standardised set of verbal instructions. This was to ensure participants understood what was needed from them and when they could start lifting. A secondary purpose of the verbal commands was to standardise each start and endpoint of the deadlift movement. This made it easier to define where the start and endpoint of the sets were on the raw EMG trace. The 5RM protocol was only performed in visit one as this was solely to predict 1RM for visit two and three. Three minutes was given at least to recover the anaerobic energy systems (Willardson, 2008). Immediately after each set was complete, the participant reported an accurate perceptual reading of their RPE, and HR was noted. If the participants were successful with every five repetitions at the set increment, during the three minutes of rest, the lead researcher and trainer would assess the speed of repetitions and the reported RPE and base the decision on this information to make a judgement on the percentage of weight lifted on the participants next increment (%) and load the bar. The focus was to ensure the participant was reaching their maximal 5RM within five sets of five repetitions. This was pilot tested prior to

experimental trials. The standard procedure was to follow a routine set of increments; set 1 at 75%, set 2 at 85%, set 3 at 95%, set 4 at 100% and set 5 was allowed to give room if the participant was not at their full maximal 5RM capacity; if 100% was reached with further sets to go and participants RPE was not close to maximum. Only a maximum of five sets was allowed in the protocol, this was to avoid failure due to chronic fatigue (Reynolds et al, 2006). The increments would then increase by 1%. The percentage of weight lifted was calculated using a master baseline excel spreadsheet. Surface EMG was recorded for every five repetitions for five sets. The final weight lifted on participants' final set was considered as the participants 5RM. This correlates to 87% of their expected 1RM lifting performance (Reynolds et al, 2006) which were subsequently calculated (if 5RM = 100kg; predicted 1RM = 100*1.1307 = 113kg). The predicted 1RM value was used to determine the weight attempted for the familiarisation task and Dynamic Lifting Task (DLT) to assess the performance effect of L-Menthol spray against the control-spray in visits two and three. In short, the DLT was to complete 10 repetitions at a sub-maximal value of 75% of predicted 1RM in visit two and three. This was in accordance with Baechle and Earle (2008) who used this as an indicator of resistance exercise performance.

Figure 4. An image of a participant performing the deadlift manoeuvre with a hexagonal bar from the starting position (top panel) and on movement completion (bottom panel); participants could drop the bar if they were unable to lift the weight.

3.4.2 Isometric Lifting Task

During the three-minute rest period after the 5RM protocol, participants watched a brief video clip of an isometric maximal mid-thigh pull technique. Participants were free to undertake any static and dynamic stretching of the specific muscle groups related to the mid-thigh pull. The mid-thigh pull is an isometric exercise involving static contractions and no visible movement at the joint angles. Participants were then shown a brief demonstration of the required stance and technique requested by the lead researcher. The trainer supervised the IMLT to make certain the correct movement was being executed by the participant. Any questions asked by

the participant about the IMLT were answered by the trainer. Once the rest period was complete from the DLT, the participant was asked to report their RTT. Participants' maximal isometric lifting performance was assessed using a mid-thigh pull manoeuvre (see figure 5).

Figure 5. An image of a participant performing a mid-thigh pull manoeuvre on a back-strength dynamometer.

The dynamometer was calibrated before use. The performance measurement measured in kilogram-force (KGF) is generated by the participant creating ground reaction force by pulling up against the hand-held bar attached and held at a fixed height. Participants were asked to step on to the dynamometer. With consultation from the trainer, the position of the bar was adjusted according to the participant's height and for their joint angles at the hip and knee, to be in the correct range of measurement at which a mid-thigh pull was to be executed. These angles were; knee, between the ranges of 125° and 145° and the hip, between 140° and 155° (Beckham et al, 2013; Dobbin et al, 2017). The angles and bar placement were recorded (within-participant) on the first visit and replicated in visits two and three. The joint angles were measured using a goniometer. Participants were to have minimal tension on the bar, however providing enough

strength to hold the bar vertically up. Participants were told no countermovement or leaning backwards was allowed. Elbows to be straight and shoulders ever so slightly positioned over the bar. The bar had to be at mid-thigh height before the task began. The muscular force generated was whilst the muscle is at a fixed length. Participants completed three brief WU attempts for three seconds at 25%, 50% and 75% intensity before maximal attempts commenced.

Once completed, participants rested for 90 seconds before the recorded angles were measured a second time ready for the maximal IMLT attempts. This rest period was standardised between each of the maximal lifts. If countermovement occurs or if the change of body position is too great, the attempt will be counted as an invalid attempt; the deployment of the correct technique was carefully policed by the experimental team for each lift. Participants were asked to maintain a maximal effort (pull) for three seconds. Immediately after, they reported their RPE and HR. Surface EMG was recorded parallel to the isometric mid-thigh pull movement (recorded for three seconds). Participants were asked to complete three attempts of the maximal isometric pull. Participants were asked to follow the same set of verbal instructions as before in the 5RM protocol. The analogue dial was set to 0 KGF manually on the dynamometer. This was standardised throughout all visits. During each three-second maximal attempt, the lead researcher would verbally state “pull, pull, pull, pull, pull”. This was standardised on every attempt made by each participant.

3.4.3 Familiarisation

After the three-minute rest period was complete from the IMLT, participants then completed a familiarisation of the DLT which was to be performed in visit two and three. The familiarisation task was only performed once and only in the baseline test. Participants performed the deadlift manoeuvre (see figure 4). During the three-minute rest period, the hexagonal bar was loaded

to 75% of the participants calculated 1RM. Participants attempted five repetitions rather than the 10 that would be required in visit two and three (Reynolds et al, 2006). Participants reported their RTT using the corresponding perceptual scale. The participants then attempted to lift five repetitions. No encouragement was given to the participant whilst lifting. RPE and HR were recorded immediately after completion of the familiarisation set. Participants were asked to complete a standardised cool down period of five minutes sub-maximal cycling on a static exercise bike. After the prescribed cool down activity on the cycle ergometer, participants typically completed self-directed static and dynamic stretching of the major muscle groups involved in the weightlifting. Following this, participants were free to leave the S and C suite.

3.5 Visit two and visit three: Experimental Trials

One hour prior to each second and third visit, the sports laboratory technician would prepare the intervention (control-spray or L-Menthol solution) inside a spray bottle. Participants reported their RTT, HR and additionally their thermal perceptions on arrival at the S and C suite (see perceptual measurement section). They were then asked to complete the standardised cycling WU for five minutes.

During the WU, the dry box weight (the box participants will be standing in when the control-spray or L-Menthol spray is applied) was measured prior intervention application. This was a control measure to observe how much liquid spray residue (runoff weight) was left in the box and how much of the solution has been applied to the legs. The temperature of the liquid spray was checked using a thermistor. Humidity and environmental temperature were recorded. Once the WU was complete participants reported their, HR, TS_{wb} and thermal comfort (whole-body) (TC_{wb}) and only reported a second reading if participants thermal sensation (legs) (TS_{legs}) and thermal comfort (legs) (TC_{legs}) felt differently. This was stated and standardised at every measurement point of these values. After the prescribed WU on the

cycle ergometer, participants were then free to complete stretching of the major muscle groups involved in the weightlifting tasks and then asked to be seated. An adhesive rectangle strip was then applied to the participant's RF, BF and MG in the same anatomical position where the permanent marker was applied from the previous baseline visit. The adhesive strip was then protected by a larger rectangle piece of polypropylene which was cut prior to testing. This was attached by applying breathable tape (TransporeTM,1527-1, 3M Health Care, MN, USA). The purpose of this was to protect the adhesive strip from the moisture and spraying (wetness) of the intervention as the physical electrode was not water-resistant. Pilot testing verified that the integrity of the connection between the EMG sensor and skin was not compromised by liquid ingress from the spray under the adhesive strips. Participants were then instrumented with three external skin thermistors and secured with Transpore tape. The skin thermistors were attached to the opposite leg of the leg the EMG electrodes were to be placed. This was done to minimise risk. If we used the side where the EMG sensors were (dominant leg of the participant) there was the risk of interference between the sensors; physical as well as mechanical/electrical. Secondly, the loading and unloading of the weights took place from the right of the participant so locating the sensors on the right-hand side would have introduced a trip hazard. This rationale for this placement was established in pilot tests.

One thermistor each was placed at the quadricep, hamstring and calf. Thermistors were similarly standardised for placement to the EMG sensors although standardisation between tests (i.e. lab visits) did not occur using the marker pen system.

The participant was asked to remove their shoes and socks and apply a face mask. This covered and protected the mouth and nose to limit scent and inhalation of the intervention. This was controlled as a study conducted by Eccles, Griffiths, Newton, and Tolley (1988) showed L-Menthol was the only isomer to give participants a cooling sensation and gave a sensation of

increased nasal airflow. Participants were then asked to carefully step inside the plastic box. A large blue towel was put underneath the box to absorb the moisture and for the participants to be able to dry their feet post-application of the control-spray or L-Menthol spray (see figure 6). Experimental trial duration was recorded on a master stopwatch with key events within the protocol noted against time, such as; the start and end time of spray administration, the start and end of the DLT (duration of lift) and start and end time of the IMLT (end of IMLT is the end of the trial). The experimental trials were aimed to be 25 minutes or under. This specific time was selected due to previous research conducted (Barwood et al., 2014; Gillis et al., 2010) which used the same time protocol of 25 minutes for trial completion and to ensure it was in the range of the chemically active period of L-Menthol. The master stopwatch was also used to standardise the start time of the intervention application for each trial at 2 minutes. Once the participant was in place, the lead researcher started the master stopwatch and the data logger, in which two minutes of resting data were recorded. During the standardised 2 minutes, the spray bottle was carefully removed from the temperature-controlled water bath. Once the spray was weighed and the 2 minutes was reached, the control-spray or L-Menthol spray was administered (see figure 6). Once volume applied was reached, the time taken to spray was recorded and the volume of spray remaining was recorded. Once spraying administration was complete, participants reported their RTT, TS and TC (see figure 3). The weight of the box was weighed and recorded.

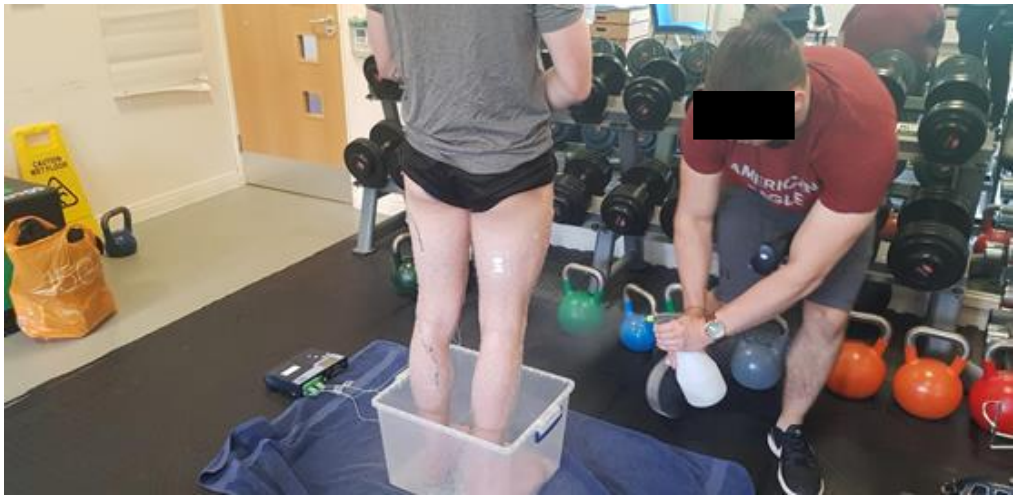

Figure 6. Lead researcher administering either the control-spray or L-Menthol spray, covering both legs in the solution.

Participants always kept the face mask on until told to remove. The lead researcher then removed the polypropylene sheet and attached the EMG electrode onto the adhesive strip and turned it on. Participants were then asked to walk over to the DLT area which they then removed their face mask which was disinfected and cleaned post-experimental trial. Prior to the visit, the bar was loaded with a sub-maximal load equivalent to 50% of their predicted 1RM calculated from the baseline visit. A SWU was then performed consisting of two sets of five repetitions. Participants then had a three-minute rest period, during which the hexagonal bar was loaded to 75% of their predicted 1RM. This was the same weight lifted in visit one, in the familiarisation task. Participants reported their RTT, TS and TC. Once the participant was ready and in position to lift, they were asked to follow the standardised set of verbal instructions. Surface EMG data were recorded throughout the start of the DLT to the end of the lifting sequence. Participants were told to attempt 10 completed repetitions. Once complete, immediately, participants reported RPE and HR.

Participants had a maximum of three-minutes rest in which they then moved onto the IMLT. Participants reported their RTT, TS and TC. Participants then completed three brief attempts at 25%, 50% and 75% sub-maximal intensity. Once complete, participants were then measured

at the knee and hip angles using the same standardised angle measurements which were recorded from the first visit using the goniometer. Participants followed the standardised set of verbal instructions. RPE and HR were recorded immediately after each attempt. Once all attempts were complete, all instruments were removed (EMG electrodes, HR monitors and thermistors).

Participants were then asked a series of questions which participants gave their subjective response. Participants then completed the cool down procedure on the cycle ergometer. After the prescribed cool down, participants typically completed self-directed static and dynamic stretching of the major muscle groups involved in the weightlifting. On the participants final visit when the study concluded, the participant was given a debrief form to read thoroughly (see appendix F). To maintain the blinding of test conditions an independent member of the research team (i.e. the independent member of the research team was not in the room at the time of data collection) administered the debrief with the lead researcher out of the room. Briefly, participants were asked to circle their response to which intervention they believed they received in visits two and three (see appendix F for the question asked, at the bottom of the debrief form).

3.6 Description of L-Menthol Spray and Control Spray

Both sprays were produced by the same independent chemical consultant who has produced the sprays for previous studies (Chemical Associates, Rosemead, Frodsham, United Kingdom; see Barwood et al, 2012, 2014, 2015 & 2019). The control-spray contained 3% surfactants mixed in water, while the L-Menthol spray contained a concentration of 0.20 wt/wt L-Menthol in 3% surfactants plus water. The only difference between the solutions was the L-Menthol component. To minimise supplementary perceptual cooling associated with the spray temperature lower than exercising skin temperature, ambient temperature and core body

temperature, the spray bottles containing the solutions were immersed in a temperature-controlled water bath (4YANG Digital Thermostatic Bath Water Lab), held at 35.5°C (Tempette Junior TE 8J, Techne, Cambridge, U.K), (see figure 7) 1-hour before each trial commenced. The spray bottle was secured inside the water bath with two rubber bands and two 1kg dumbbells to prevent the spray bottle from tilting, and to avoid non-uniform warming of the solution inside the bottle. The bath temperature was verified by a calibrated thermistor (Grant Instruments, Cambridge [Shepreth], Cambridge, U.K) immersed in the water pre-experimental trials. The agreement between bath and spray temperature was verified in pilot tests.

To ensure a consistent volume of solution was applied on each visit, spray volume was measured using a calibrated digital weighing scale (Sartorius Mechatronics UK Ltd, TE6100, Surrey, U.K; 1 g resolution) by measuring the pre and post-application spray bottle weight and by frequently weighing the bottle during the spraying process. The calculated volume of spray to be administered was aimed for 100ml. However, in pilot tests, runoff weight (into the box) was larger than expected, therefore an increased amount of spray was needed to be applied to attempt to apply 100 mL of L-Menthol to the legs. The spray aperture was standardised with both spray bottles in the same pilot tests and set and was not changed during experimental trials. The same lead researcher applied the spray on each occasion. A standardised period of three minutes maximum was practised and confirmed in pilot tests to apply the 100 mL of solution using the same practised technique by the same researcher. The duration and quantity of spray administration were in conduct with previous research (Barwood et al., 2014; Barwood et al., 2015).

Figure 7. *An image of either the control or L-Menthol solution inside the spray bottle and submerged in a temperature-controlled water bath and the temperature was set at the start of the study and was not changed.*

3.7 Measurements and Standardisations

Participants underwent a thorough explanation of each perceptual and thermal scale before commencing the exercise trials. Both thermal perceptions were asked as a whole-body perception and asked a second time as legs specific and only used in visit two and three. All types of measurements were at the frequencies identified in figure three.

3.8 Perceptual Measurements

3.8.1 Rating of Perceived Exertion

Participants provided a rating of their perceived exertion in the preceding weightlifting effort that relates to their whole body; RPE was reported by the participant having consulted the following scale: which ranges between 6 and 20 and where 7 = Very very light, 9 = Very light, 11 = Fairly light, 13 = Somewhat hard, 15 = Hard, 17 = Very hard, 19 = Very very hard (Borg, 1982).

3.8.2 Readiness to Train Scale

RTT was assessed on a 10 cm visual analogue scale (VAS) ranging from: Not at all ready (0 cm) to completely ready (Piacentini and Meeusen, 2015). Participants used a non-permanent marker to place a horizontal line across the 10 cm vertical line. This then was measured with a ruler, starting from 0 cm.

3.9 Thermal Perceptual Measurements

3.9.1 Thermal Sensation

Thermal sensation (TS; Zhang, 2003) was assessed for the whole body (TS_{wb}) and legs (TS_{legs}) using a 20 cm VAS ranging from "Very Hot" (20 cm); "Hot"; "Warm"; "Slightly Warm"; "Neutral"; "Slightly Cool"; "Cool"; "Cold"; to "Very Cold" (0 cm). On both TS and TC perceptual scales, the worded descriptions adjacent to the scales were used as a guide only and participants provide their rating by placing a horizontal mark along the 20 cm scale in non-permanent marker (see appendix E).

3.9.2 Thermal Comfort

Thermal Comfort (TC; Zhang, 2003): was assessed for the whole body (TC_{wb}) and legs (TC_{legs}) using a 20 cm VAS with the following words used to guide comfort voting: very comfortable (20 cm), comfortable (16 cm), just comfortable (12 cm), just uncomfortable (10.5 cm), uncomfortable (4 cm), very uncomfortable (0 cm) (see appendix E).

3.10. Physiological Measurements

3.10.1 Heart Rate

Participants wore a HR monitor (FT1, Polar Electro Oy, Kempele, Finland) and a chest strap and telemetrically linked the HR monitor watch. Between experimental trials, the chest strap was cleaned and dried in accordance with laboratory procedures.

3.10.2 Skin Temperature

T_{skin} was logged automatically every 30-seconds using a remote data logger (Squirrel 2020 series, Grant Instruments Ltd, Cambridge [Shepreth], U.K), from start to end of experimental trials. Between experimental trials, the skin thermistors were cleaned by an alcohol swab. T_{skin} were taken from the quadricep, hamstring and the medial calf. Calibration of the skin thermistors and data logger were performed prior to data collection. The calibration was executed by immersing the thermistors into warm water and using a thermometer as a control reading to calibrate the thermistors and data logger. T_{skin} was measured to observe any temperature changes of the total area of T_{skin} of the quadricep, hamstring and medial calf muscles.

3.11 Performance Measurements

3.11.1 Dynamic Maximal Lifting

The number of full repetitions completed during each dynamic maximal lifting task was counted. A full repetition of the deadlift exercise is as follows; feet between hip and shoulder-width apart, squat and keep back rigid and flat, hands slightly wider than shoulder-width apart, chest and head are held up and out (Graham, 2000). The participant then initiated the deadlift by extending hips and knees at the same rate, keep weight over the middle of the feet and to keep their back rigid and flat, elbows fully extended and lift upwards shifting the weight through the heels and legs. Participants then simultaneously extended the hips and knees until they were in a fully vertical torso position and the barbell is in line with the knees. On the descent, participants kept their back flat and flexed the hips and knees and lowered the hexagonal bar back to the floor in a controlled manner. Once the plates touched the floor, this was classed as one full repetition (Graham, 2000).

3.11.2 Isometric Maximal Lifting

Participants' maximal isometric lifting performance was assessed by performing a mid-thigh pull lifting manoeuvre. Participants manoeuvred whilst standing on a calibrated back-strength dynamometer (Back Strength Dynamometer, TKK-5002 BACK-A, TAKEI, Japan, Type-2). The dynamometer was calibrated in prior to full experimental use. This was done practically (see figure 8). A 10kg and 20kg sandbag (POWERBAG) was placed via the sandbag strap onto the hook on the dynamometer. Dumbbells of a smaller ranging from 1-10kg were used to calibrate. The analogue dial then displayed the weight the dynamometer was holding. This ensured maximum accuracy in experimental trials with participants.

Figure 8. *An image of the back-strength dynamometer being calibrated for experimental trial use.*

The measurement of the joint angles was revised and practised before experimental trials. The lead researcher and trainer revised the practices of measurements and practised using the

goniometer on the knee and hip joints. This was to avoid any complication using the goniometer and to ensure measurements were attained quickly and accurately. Two joint angles were used; knee between 125° and 145° and hip between 140° and 155° which have been utilized in previous studies (Beckham et al, 2013 and Dobbin et al, 2017).

3.11.3 Muscle Electromyography

Surface muscle EMG data was generated according to the procedures of Goodall and colleagues (2017) and in accordance with SENIAM guidelines (de Luca, 2002). Surface EMG data were collected from the agonist and antagonist muscles involved in the mid-thigh pull and the deadlift. These muscles are the RF (quadriceps), MG (medial calf muscle) and BF (hamstring muscle) (Bezerra, 2013; Escamilla, Francisco, Kayes, Speer & Moorman, 2002; Basmajian & Blumenstein, 1980). The RF, BF and MG were chosen due to previous research testing these individual muscles for research involving comparisons of EMG activity in the RF, MG and BF in different variations of the deadlift exercise (Lee et al, 2018; Andersen et al, 2018; Escamilla et al, 2002). Lee and colleague (2018) conducted a study on EMG activity comparison between the conventional deadlift and Romanian deadlift, which saw significantly greater EMG values in the RF in the conventional deadlift compared to the Romanian deadlift. Lee and colleagues (2018) concluded, the conventional deadlift would be a better technique for training the RF. Similar results were seen by Escamilla and colleagues (2002), which saw overall EMG activity from the MG significantly greater in the conventional style deadlift compared to the sumo style deadlift. In addition, Andersen and colleagues (2018) saw greater activation of the BF during the lower part of the movement of the barbell and hex bar deadlift when compared to hip thrusts. In conclusion, the research shows when moderate to high EMG activity is seen from each area of the hamstrings, gastrocnemius and quadriceps, it is suggested

higher peak forces and overall strength is seen when performing the deadlift manoeuvre (Escamilla, 2002). These anatomical locations were identified by palpation, using a ruler and guidance from SENIAM (de Luca, 2002). Once located, the area for EMG strip attachment was shaved, abraded and cleaned correspondingly to the muscle belly. These positions were marked with a marker pen and participants were allocated a pen to maintain the markings of the locations. The electrodes placed at each site were placed in a standardised position and stuck to the skin using adhesive strips (Delsys Trigno wireless EMG system, Delsys USA). Surface EMG data were amplified (9100), band-pass filtered (50-500 Hz) and sampled at a frequency of 2000 Hz. Standard EMG waveforms were generated for each recorded maximal and sub-maximal muscle contraction. These waveforms were analysed offline using Delsys acquisition programming to generate the root mean squared (RMS) of each of the raw surface EMG traces of the RF, BF and MG. The EMG traces of the active muscles change in which (reductions) are indicative of muscle fatigue.

3.12 Semi-Structured Interview and Subjective comments

Following the completion of visit two and three, participants were asked a series of standardised questions about the interventions (see table 2) without the intervention blinding being revealed. Each question was answered based on the participants' experience from the experimental trial (i.e. subjectively).

Table 2. *A table displaying questions asked at the end of visit two and three.*

Participant after-trial Questions
1. How did the spray feel when applied? 2. Did you feel that the intervention affected your performance in any way? 3. How do you feel now after the experimental trial? 4. Do you have any other comments to be made about the interventions or the experimental trial?

3.13 Data Analysis

Mean (±SD) data were calculated for perceptual ratings (RTT, RPE, TS_{wb} TS_{legs} & TC_{wb}, TC_{legs}), performance indices (repetitions and force production), rmsEMG T_{skin}, environmental variables: box weight (i.e. spray run-off), spray volume, spray duration, ambient temperature and relative humidity. The normality of distribution of data was checked using Shapiro Wilks analyses. Where data between two-time points or conditions were compared, comparisons were made using a paired samples t-test if data were parametric or a Wilcoxon signed ranks test if data were non-parametric. Where more than two-time points were compared between conditions, data were compared within-participant between condition using a repeated measure analysis of variance (ANOVA). Non-spherical data sets, indicating unequal variance, were adjusted using Mauchly's test. Statistically significant effects were determined post-hoc using *Fishers LSD* pairwise comparison. Data analyses were conducted using SPSS (SPSS v 26, IBM, Chicago, Illinois, USA) and Prism (Graphpad, Prism v 6, San Diego, USA) to an alpha level of 0.05.

The following analyses were undertaken for comparisons between conditions, between DLT and IMLT:

3.13.1 Conditions

Mean (±SD) paired data were compared between condition for variables relating to spray application (i.e. spray volume, duration, run-off) and environmental conditions (i.e. ambient temperature, relative humidity). The skin temperature response was analysed using a higher resolution analysis using five distinct time points (Rest, 5 min, 10 min, 15 min, 20 min) to establish if any vasoconstriction had occurred as a consequence of the menthol application. Data were compared between conditions by repeated measures ANOVA between on data normalised to the starting T_{skin} measurement.

3.13.2 DLT

The total number of repetitions were compared using the Wilcoxon signed ranks test. RPE and HR were compared between condition for the time point immediately after the DLT was complete using a paired-samples t-test. Perceptual measures (i.e. TS_{wb}, TS_{legs}, TC_{wb}, TC_{legs}) were compared within-participant between condition for 3-time points: post-WU, post-spray application and pre-DLT. The rmsEMG data were compared for DLT of the RF, BF and MG at three-time points; repetition 1, repetition 5 and repetition 10. F-test (df), *p* value and partial eta squared (as an indicator of effect size) are reported for ANOVA main effects. RTT was compared for the two-time points immediately after spraying and immediately prior to the DLT.

3.13.3 IMLT

RTT, TS_{wb}, TS_{legs}, TC_{wb}, TC_{legs} for the time point immediately before the first IMLT commenced were compared between condition using a paired samples T-test. The total force production produced during the IMLT was calculated for each 3-second isometric contraction and was compared across the three repetitions performed in each condition. Similarly, RPE and HR were compared for the three-time points immediately after the IMLT was performed. The rmsEMG data were compared for the RF, BF and MG as an average of that seen over the 3-second contraction period at three-time points; repetition 1, repetition 2, repetition 3.

Chapter 4

4. Results

4.1 Baseline test (visit one)

Except for three participants, all participants required five sets of incremental steps to establish 5RM in completing the baseline test to establish the weight to be lifted in the DLT. Participants' mean (±SD) RPE and HR were respectively 19 ± 1 and 157 ± 15 $b.p.m^{-1}$ which indicated the

participants had reached a maximal intensity during their baseline 5RM protocol. All 1RM values were calculated subsequently using the calculation; (Final 5RM value) *1.1307 = 1RM. The 75% was calculated; (1RM value) *0.75 = 75% of 1RM (see table 3).

Table 3. Baseline data of all 12 participants final 5 Repetition maximum lifted, the number of repetitions completed in the final 5 repetition maximum, calculated 1 repetition maximum, and the calculated 75% of participants 1 repetition maximum (n=12).

Participants	Final 5RM Lifted (Kg)	Repetitions completed of final 5RM	Calculated 1RM (Kg)	75% of 1RM (Kg)
1	117.2	5	132.5	99
2	124.7	3	140	105
3	87.2	5	98.5	74
4	147.2	5	166.5	125
5	107.2	5	122	91
6	130	5	147	110
7	142.2	5	160	120
8	187.2	5	211.5	158
9	147.2	5	166.5	125
10	127.2	5	144	108
11	177.2	5	200	150
12	137.2	5	155	116
Mean	136	4.8	153.8	115
±SD	27.6	0.57	31.2	23

4.2 Control Spray and L-Menthol Spray Conditions (Visits 2 & 3)

4.2.1 Environmental Conditions

The mean (±SD) of the ambient temperature averaged 16.8 ± 0.79 ºC and 17.1 ± 0.64 ºC in the control-spray and L-Menthol spray conditions, respectively. The conditions did not differ (t = 1.236, p = .242). Relative humidity (RH) averaged a mean (±SD) of 43 ± 7% and 43 ± 7% in the control-spray and L-Menthol spray conditions respectively and the conditions did not differ (t = .3046, p = .766).

4.2.2 Spray Volume, Duration and Run-Off (box weight)

The mean (±SD) for the spray volume averaged 124 ± 6.6 mL and 124 ± 6.8 mL in the control-spray and L-Menthol-spray conditions, respectively. These data were not normally distributed and consequently, a non-parametric Wilcoxon signed ranks test was conducted and no significant difference between (p = .7148). Spray duration data were abnormally distributed and averaged a mean (±SD) of 213 ± 26 (s) and 219 ± 32 (s) in control-spray and L-Menthol spray conditions respectively and were not different between the conditions (p = .7109). The amount of run-off as estimated by change in box weight before and after spraying was similar in each condition and averaged a mean (±SD) of 34.8 ± 7 mL and 37.8 ± 8 mL in the control-spray and L-Menthol spray conditions respectively which were not different *(*t = 1.026, p = 0.326).

4.3 Perceptual Responses

4.3.1 Readiness to Train

Dynamic Lifting Task

After spraying was complete, participants mean (±SD) of their RTT was 7.6 cm ± 2 and 7.6 cm ± 3 in the control-spray and L-Menthol spray conditions, respectively. This was closest to the worded descriptor *completely ready to train*. Prior to the DLT, participants RTT was similar to that given following the spray application and averaged a mean (±SD) of 8.3 ± 2 cm and 8.1 ± 2 cm, respectively. Due to these similarities there was no significant difference between conditions prior to DLT (t = .0615, p = .550).

Isometric Lifting Task

The mean (±SD) of the RTT was unaffected prior to IMLT and averaged 8.25 ± 1 cm and 8.3 ± 2 cm in control-spray and L-Menthol spray respectively (t = .2012, p = .844).

4.4 Thermal Perception Responses

4.4.1 Thermal sensation

Dynamic Lifting Task (Thermal Sensation Whole-body)

Specific to the whole body, the mean (±SD) after the WU, participants TS_{wb} was 14.1 ± 2 cm and 13.6 ± 3 cm in the control-spray and L-Menthol spray conditions, respectively. This was closest to the word descriptor *slightly warm.* Post-spraying, participants felt similar in the control-spray condition but was subjectively (not statistically) cooler in the L-Menthol spray condition, TS_{wb} averaged a mean (±SD) of 12.6 ± 2 cm and 11.9 ± 2 cm, respectively. This was closest to the word descriptors *slightly warm* and *neutral.* Prior to DLT, participants felt similar to that of after the WU (i.e. *slightly warm)* and averaged a mean (±SD) of 13.1 ± 2 cm and 13.3 ± 2 cm, respectively (see figure 9). There was an effect over time: $f_{(2,22)} = 6.420$, $p = .006$, $\eta p2 = .369$ but no significant main condition or interaction effect: $f_{(1,11)} = 1.566$, $p = .237$, $\eta p2 = .125$; $f_{(2,22)} = .480$, $p = .625$, $\eta p2 = .042$, respectively.

Isometric Lifting Task (Thermal Sensation Whole-body)

Similarly, participants TS_{wb} were unaffected between either spray intervention prior to IMLT and the mean (±SD) averaged 14.3 ± 1 cm and 13.5 ± 2 cm in the control-spray and L-Menthol spray conditions; i.e. participants felt between *warm* and *slightly warm* in the control-spray condition and *slightly warm* in the L-Menthol spray condition which was not different ($t = 1.439$, $p = .178$).

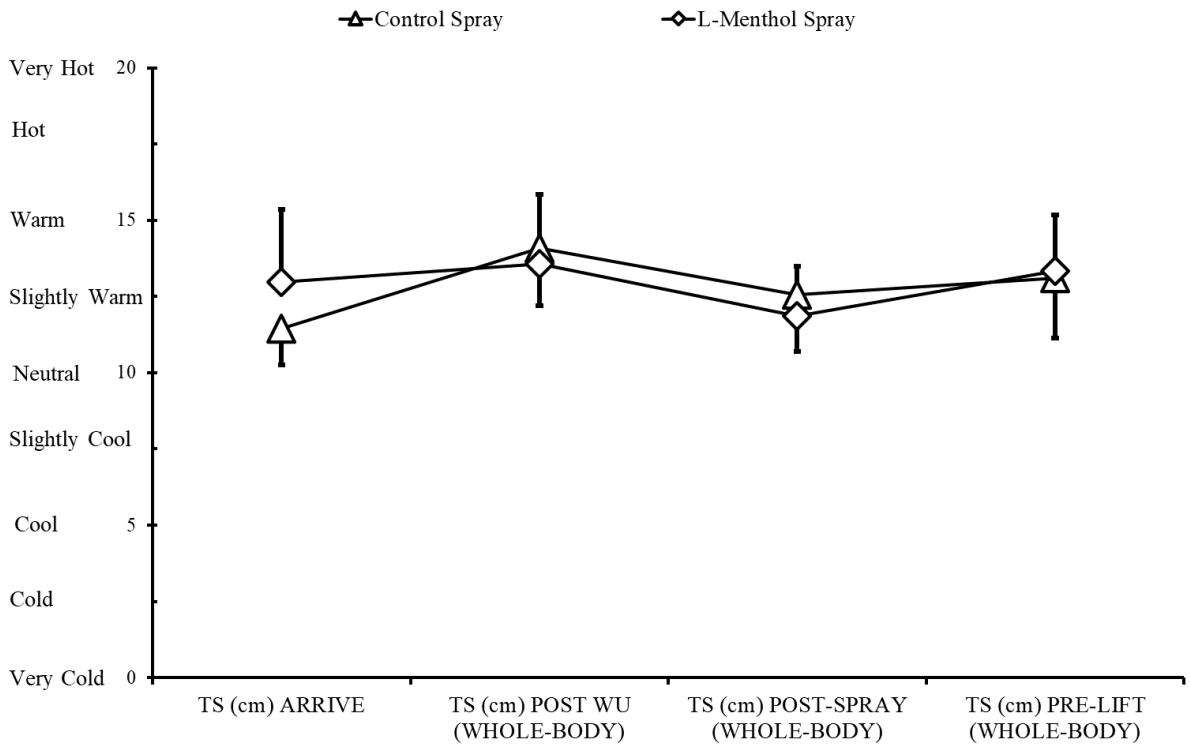

Figure 9. A line graph showing the average TS_{wb} response of the control-spray and L-Menthol spray at arrival, post-WU, post-spray and prior to the DLT (n = 12).

Dynamic Lifting Task (Thermal Sensation – Legs)

After the WU, participants TS_{legs} mean (±SD) averaged 14.9 ± 2 cm and 14.5 ± 1 cm and were very similar in the control-spray and L-Menthol spray conditions, respectively. This corresponded to the worded descriptors *warm* to *slightly warm,* respectively. Post-spraying, participants felt cooler in both conditions and averaged 8.2 ± 3 cm and 7.6 ± 3 cm. This was closest to the word descriptor *slightly cool*. Prior to DLT, participants TS_{legs} averaged a mean (±SD) of 9.4 ± 3 cm and 7.7 ± 3 cm in the control-spray and L-Menthol spray conditions respectively which was only subjectively (not statistically) lower in the L-Menthol spray condition; corresponding to the worded descriptor *slightly cool* compared to *neutral*. Similarly, to TS_{wb}, there was a significant

time effect: $f_{(2,22)} = 60.728$, $p = .001$, $\eta p2 = .847$, but no main condition or interaction effects: $f_{(1,11)} = 2.486$, $p = .143$, $\eta p2 = .184$; $f_{(2,22)} = .951$, $p = .402$, $\eta p2 = .080$, respectively (see figure 10).

Isometric Lifting Task (Thermal Sensation – Legs)

Prior to the IMLT, both descriptive and statistically significant differences were seen in TS_{legs} because of L-Menthol spraying ($t = 2.233$, $p = .047$). Participants' TS_{legs} averaged a mean (±SD) of 12.9 ± 3 cm and 9.6 ± 4 cm in the control-spray and L-Menthol spray conditions respectively which corresponded to the worded descriptor *slightly warm* and *neutral*.

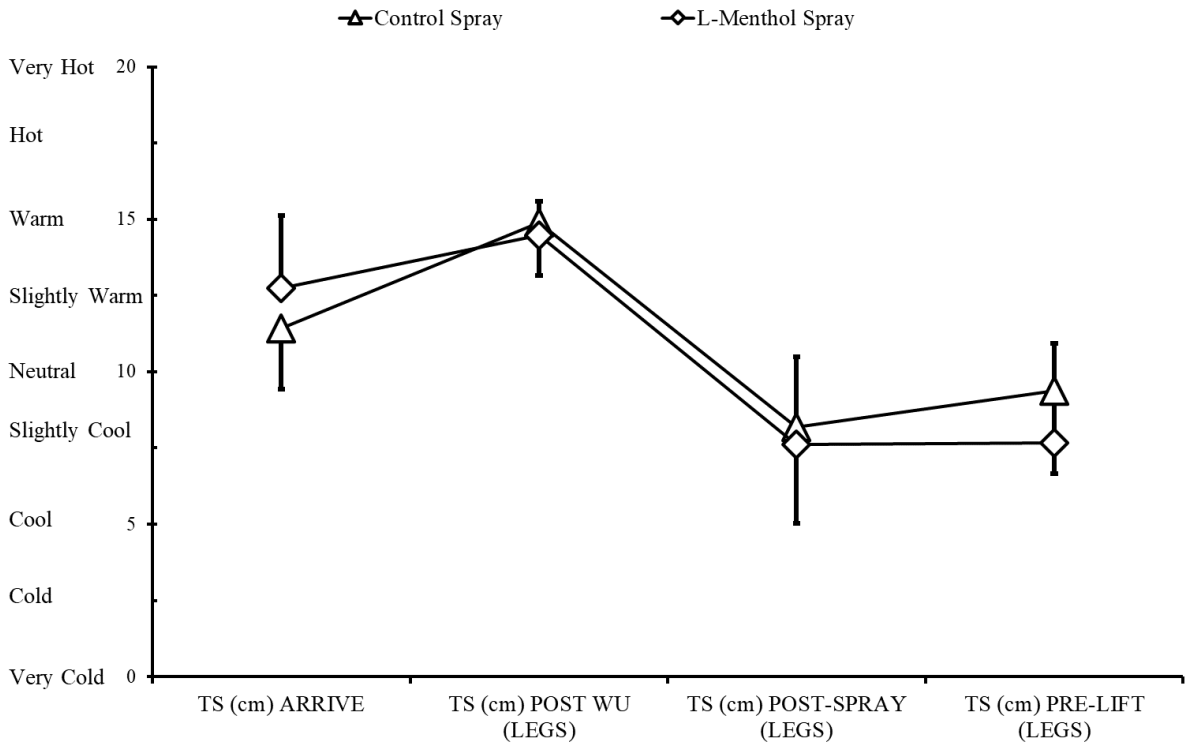

Figure 10. A line graph showing the average TS_{legs} response of the control spray and L-Menthol spray at arrival, post-WU, post-spray and prior to the DLT (n=12)

4.4.2 Thermal Comfort

Dynamic Lifting Task (Thermal Comfort Whole-body)

After the WU, the mean (±SD) of participants TC_{wb} was 13.5 ± 2 cm and 13.1 ± 3 cm in the control-spray and L-Menthol spray, respectively. This was closest to the word descriptor *just comfortable*. Similarly, to that of after the WU, post-spraying averaged a mean (±SD) of 13.3 ± 3 cm and 13.9 ± 2 cm, respectively. Prior to the DLT, participants felt similar to after the WU with the control-spray but descriptively (not statistically) slightly more comfortable with the L-Menthol spray and averaged a mean (±SD) of 13.6 ± 1 cm and 14.5 ± 2 cm respectively. This corresponded to the word descriptors *just comfortable* and *comfortable*, respectively (see figure 11). Despite this descriptive change between the control-spray and L-Menthol spray conditions, statistical analyses showed no significant main condition, time or interaction effects: $f_{(1,11)} = 1.185$, $p = .300$, $\eta p2 = .097$; $f_{(2,22)} = 1.267$, $p = .301$, $\eta p2 = .103$; $f_{(2,22)} = 1.124$, $p = .343$, $\eta p2 = .093$, respectively.

Isometric Lifting Task (Thermal Comfort Whole-body)

However, prior to the IMLT, participants felt significantly ($t = -2.336$, $p = .039$) more comfortable in the L-Menthol spray condition and averaged a mean (±SD) of 14.4 ± 2 cm compared to the control-spray condition of 13.1 ± 2 cm and with the worded descriptor being closer to *comfortable* than *just-comfortable*.

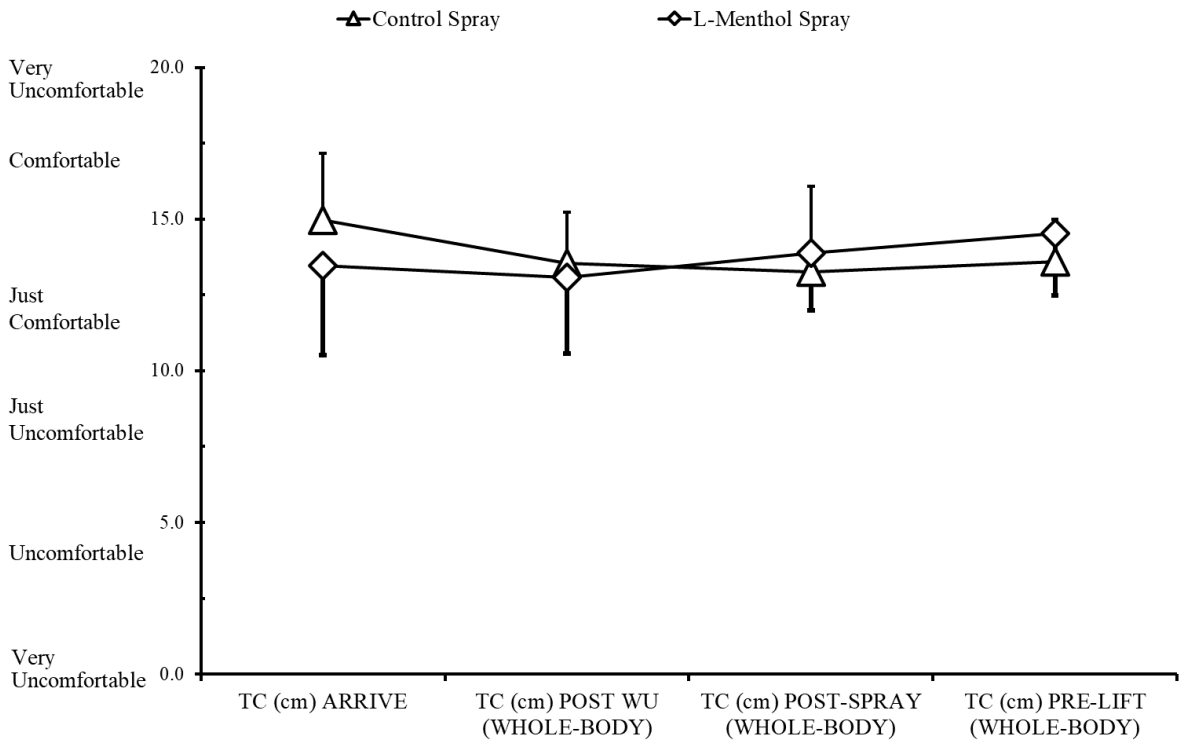

Figure 11. A line graph showing the average TC_{wb} response of the control-spray and L-Menthol spray at arrival, post-WU, post-spray and prior to the DLT (n=12).

Dynamic Lifting Task (Thermal Comfort – Legs)

After the WU, the mean (±SD) of participants TC_{legs} was similar in the control-spray and L-Menthol spray conditions respectively; 12.6 ± 3 cm and 12.9 ± 2 cm. This was closest to the word descriptor *just comfortable.* Similarly, participants felt the same post-spraying between conditions and averaged a mean (±SD) of 12 ± 4 cm and 12.3 ± 3 cm respectively and corresponding to *just comfortable*. Prior to the DLT, participants felt descriptively (but not statistically) less comfortable (11.4 ± 3 cm) in the L-Menthol spray condition than the control-spray condition (13.4 ± 3 cm). This corresponded to the word descriptors *just comfortable* and *just uncomfortable* in the control-spray and L-Menthol spray conditions respectively (see figure 12). There was no significant main condition, time or interaction effects: $f_{(1,11)} = .421$,

p = .530, ηp2 = .037; $f_{(2,22)}$ = .147, p = .864, ηp2 = .013; $f_{(2,22)}$ = 2.991, p = .071, ηp2 = .214, respectively.

Isometric Lifting Task (Thermal Comfort – Legs)

Prior to the IMLT, participants felt very similar in the control-spray and L-Menthol spray conditions and averaged a mean (±SD) of 12.6 cm ± 3 and 12.5 cm ± 4: t = .080, p = .937, respectively and corresponding to the worded descriptor *just comfortable*.

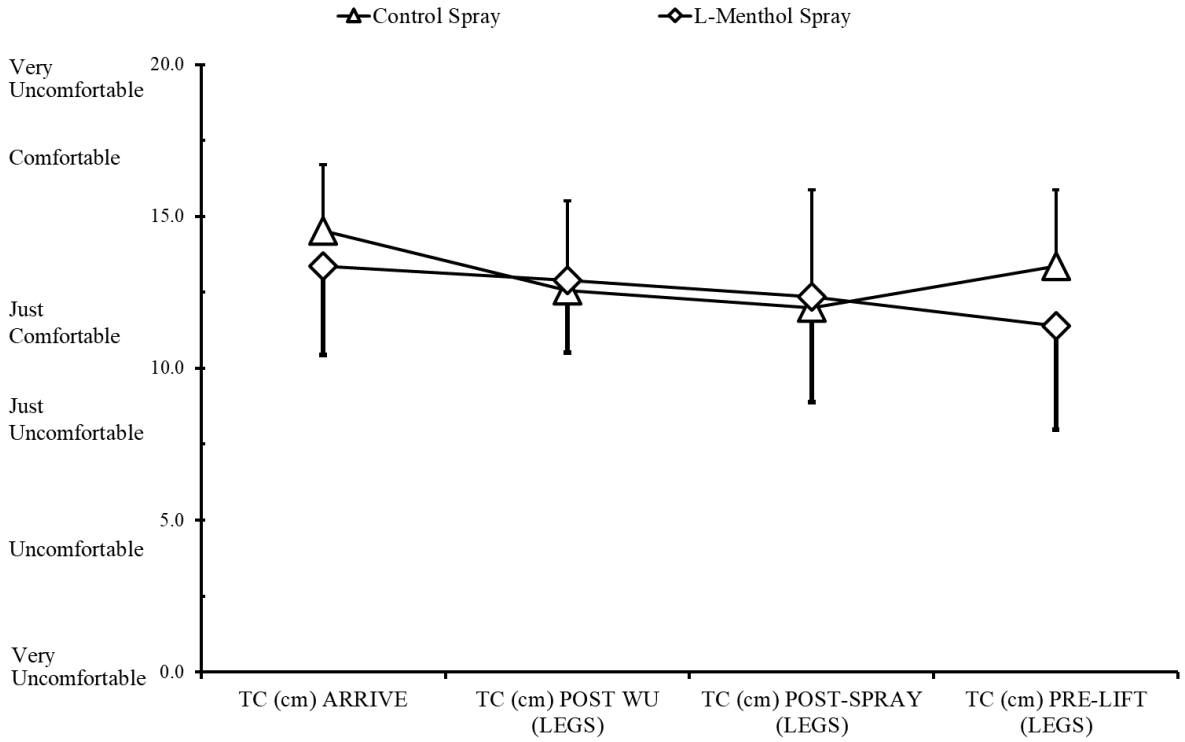

Figure 12. A line graph showing the average TC_{legs} response of the control spray and L-Menthol spray at arrival, post-WU, post-spray and prior to the DLT (n=12).

4.5 Skin Temperature

Prior to the spray application, the mean (±SD) leg T_{skin} was 30.6 ± 1.06 °C and 30.8 ± 1.06 °C in the control-spray and the L-Menthol spray conditions, respectively. Despite the spray temperature being slightly above that of skin temperature (i.e. 35.5 °C), the skin temperature dropped to an average mean (±SD) of 27.7 ± 1.20 °C and 27.8 ± 1.20 °C in the control-spray

and L-Menthol spray conditions respectively, reaching a plateau 6-minutes after spray application (see figure 13). The average mean (±SD) of the total AUC T_{skin} of the control-spray and L-Menthol spray is 54.96 ± 8.53 °C and 61.39 ± 12.3 °C (AU), respectively. Despite the visual evidence of a lower T_{skin} after L-Menthol spray application when data were normalised (see figure 6), there was no significant difference in the total area of AUC T_{skin} between control-spray and L-Menthol spray conditions (t =1.463, p = 0.1716) (see figure 14).

A higher resolution analyses was conducted at specific time points for the T_{skin} data. This was a repeated measures ANOVA between conditions (control-spray and L-Menthol spray). Five specific timepoints were used (Rest; prior spraying, 5 min, 10 min, 15 min, 20 min; mean (±SD) for both conditions shown in table 4). This was on normalised data (see figure 14). There was no significant condition effect: $f_{(1,11)}$ = 2.697, p = .129, ηp2 = .197 or interaction effect: $f_{(4,44)}$ = 1.215, p = .318, ηp2 = .099. However, a significant time effect was observed: $f_{(4,44)}$ = 237.571, p = .001, ηp2 = .956.

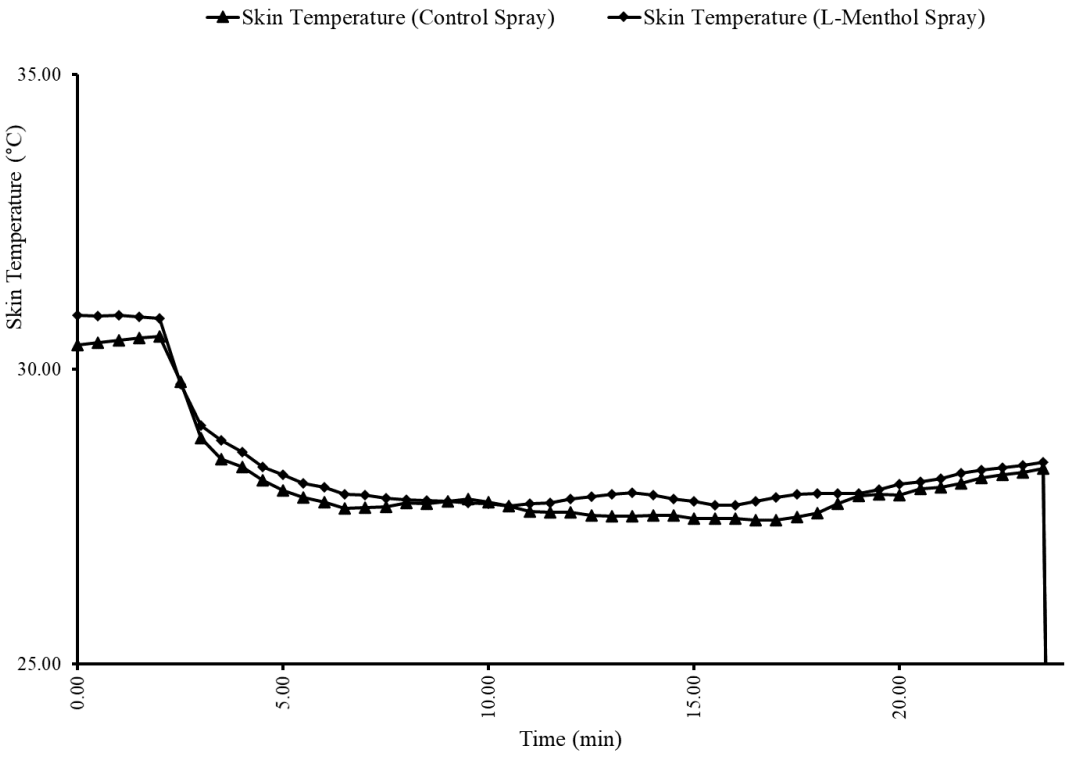

Figure 13. A line graph showing the absolute T_{skin} values between control-spray and L-Menthol spray conditions (n=12).

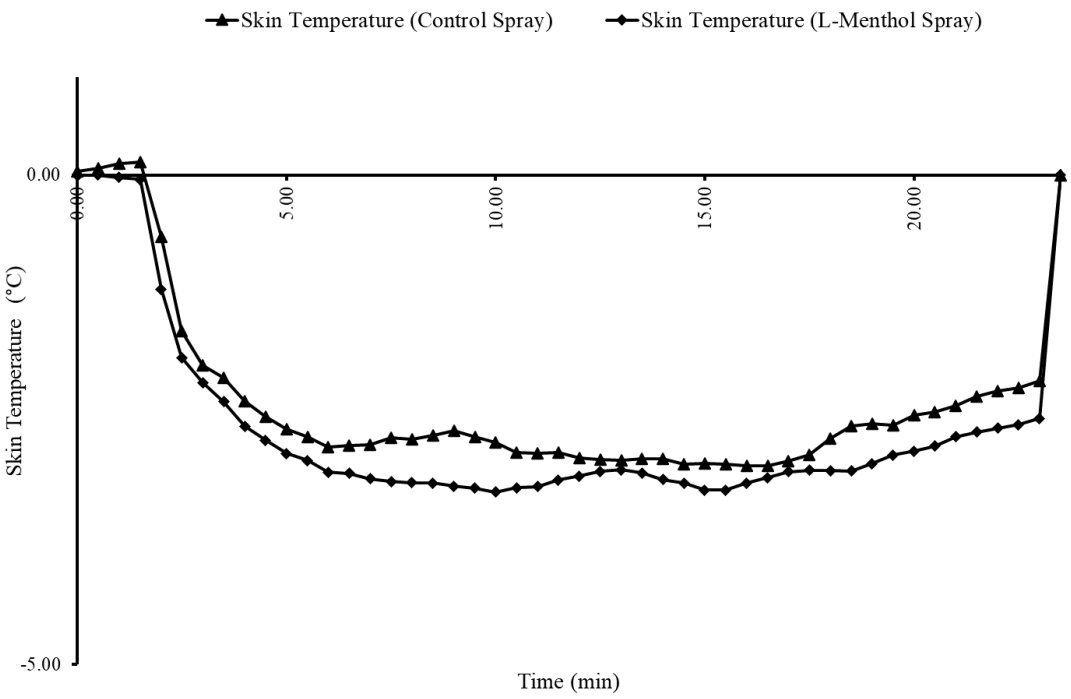

Figure 14. A line graph showing the AUC of total area T_{skin}. between control-spray and L-Menthol spray. AUC stops at 23 minutes which was the calculated average end time of experimental trials (visits 2 and 3), (n=12).

Table 4. A table showing mean (±SD) of each five-minute segment from the normalised Tskin AUC data (figure 14) between control-spray and L-Menthol spray conditions (n = 12).

	High Resolution T_{skin} Values									
	Control-spray					**L-Menthol spray**				
	Rest	**5-min**	**10-min**	**15-min**	**20-min**	**Rest**	**5-min**	**10-min**	**15-min**	**20-min**
Mean	0.04	-2.60	-2.73	-2.94	-2.45	0.00	-2.84	-3.24	-3.22	-2.82
±SD	0.07	0.47	0.38	0.54	0.59	0.08	0.45	0.72	0.87	0.72

4.6 Exercise Performance

Dynamic Lifting Task

Participants completed 10 repetitions in the control-spray and L-Menthol spray conditions and averaged a mean (±SD) of 10 ± 0 respectively. Consequently, there were no differences in the DLT repetitions (Z = .000, p = 1.000).

Isometric Lifting Task

In the IMLT, the weight pulled was similar in the control-spray and the L-Menthol spray and averaged a mean (±SD) of 138.7 ± 25.4 KGF and 141.1 ± 29.2 KGF, respectively (see table 5). However, eight out of the twelve participants in the L-Menthol spray condition pulled more weight than in the control-spray condition (see figure 15) by an average mean (±SD) of 151 ± 30 KGF and 136 ± 16.5 KGF, respectively. Nevertheless, statistical analyses showed no main condition effect: $f_{(1,11)} = .362$, $p = .559$, $\eta p2 = .032$, time effect: $f_{(2,22)} = .406$, $p = .671$, $\eta p2 = .036$ or interaction effect: $f_{(2,22)} = .797$, $p = .463$, $\eta p2 = .068$.

Table 5. A table showing the mean (±SD) of weight pulled (KGF) in attempts 1, 2 and 3 and the average weight pulled across all three attempts in the control-spray condition and the L-Menthol spray condition (n=12).

Weight Pulled (KGF) in the Control and L-Menthol Spray Conditions			
Control- spray		**L-menthol spray**	
Attempts	Mean (± SD) (KGF)	Attempts	Mean (± SD) (KGF)
Attempt 1	136.8 ± 26.4	Attempt 1	141.2 ± 31.9
Attempt 2	139.3 ± 25.9	Attempt 2	142.5 ± 30.3
Attempt 3	140.0 ± 26.0	Attempt 3	139.6 ± 27.1
Average	138.7 ± 25.4	Average	141.1 ± 29.2

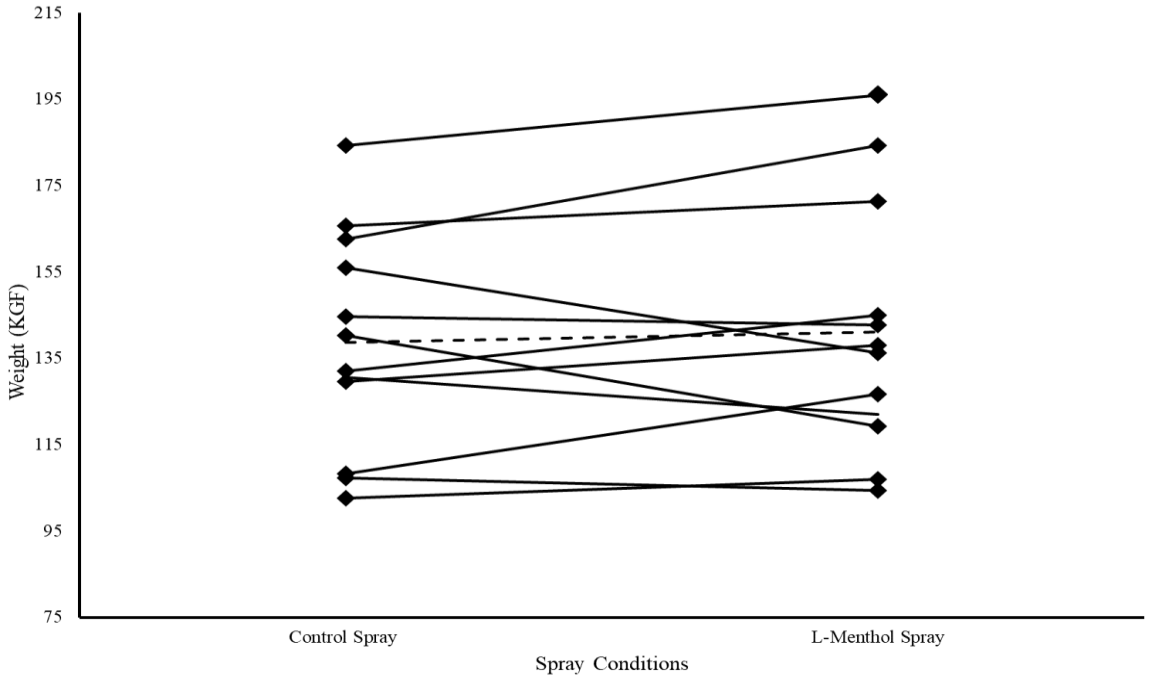

Figure 15. Participant average weight pulled in the IMLT. The dashed line indicates overall mean weight pulled across all twelve participants (n = 12).

4.7 Rating of Perceived Exertion

Dynamic Lifting Task

After the DLT, RPE averaged a mean (±SD) of 17 ± 1 and 16 ± 2 in the control-spray and L-Menthol spray conditions respectively, suggesting participants were working near maximal during DLT. There were no differences in RPE between control-spray and L-Menthol spray conditions post DLT (Z = -1.072, p = .284).

Isometric Lifting Task

After each lift in the IMLT, RPE was always within ± 1 rating between condition and the average mean (±SD) was approximately 16 ± 2 (grand mean) (equating between *hard* and *very hard*). Statistical analysis showed no effect of the control-spray and L-Menthol spray IMLT RPE perceptions; there was no main condition or interaction effect: $f_{(1,10)}$ = 2.404, p = .152, ηp2 = .194; $f_{(2,20)}$ = .905, p = .420, ηp2 = .083, respectively, but showed a significant effect over time: $f_{(2,20)}$ = 5.235, p = .015, ηp2 = .344.

4.8 Heart Rate

Dynamic Lifting Task

There was a numerically higher HR average in the L-Menthol spray than the control-spray after the DLT and averaged a mean (±SD) of 148 ± 13 b.p.m^{-1} and 145 ± 12 b.p.m^{-1}, respectively. Yet, there was no statistically significant difference in HR between control-spray and L-Menthol spray conditions post-DLT (t = -1.024, p = .328).

Isometric Lifting Task

One participant HR measurement was not recorded in one of the test conditions after IMLT so *n = 11* for HR in IMLT. Similar to the DLT, statistical analysis showed after each maximal lift of the control-spray and L-Menthol spray conditions in the IMLT, no main condition, time or interaction effects: $f_{(1,10)} = 2.206$, $p = .168$, $\eta p2 = .181$; $f_{(2,20)} = .2.574$, $p = .101$, $\eta p2 = .205$; $f_{(2,20)} = 1.997$, $p = .162$, $\eta p2 = .166$, respectively.

4.9 Electromyography

Dynamic Lifting Task

In the DLT the mean (± SD) of the rmsEMG in the RF, BF and MG are displayed in tables 6 and 7 for contraction 1, 5 and 10 in the control-spray and L-Menthol spray conditions, respectively.

Table 6. A table showing the mean (±SD) rmsEMG (v) of contractions, 1, 5, 10 in the RF, BF and MG from the DLT in the control-spray condition (n=12).

rmsEMG (v) of DLT (control-spray)			
Muscle	**Contraction 1**	**Contraction 5**	**Contraction 10**
Rectus Femoris	4.8 ± 3	6.3 ± 2.9	4.1 ± 3.1
Bicep Femoris	5.12 ± 3.12	3.19 ± 2.47	3.19 ± 2.48
Medial Gastrocnemius	4.30 ± 2.17	3.99 ± 2.08	3.76 ± 2.23

Table 7. A table showing the mean (±SD) rmsEMG (v) of contractions 1, 5, 10 in the RF, BF and MG from the DLT in the L-Menthol spray condition (n=12).

rmsEMG (v) of DLT (L-Menthol spray)			
Muscle	**Contraction 1**	**Contraction 5**	**Contraction 10**
Rectus Femoris	5 ± 2.6	5.2 ± 3	4.8 ± 3.2
Bicep femoris	3.50 ± 2.52	3.87 ± 2.68	3.78 ± 2.59
Medial Gastrocnemius	3.65 ± 2.54	3.89 ± 2.60	3.71 ± 2.43

Statistical analysis of the rmsEMG between control-spray and L-Menthol spray conditions from the DLT showed no main condition effect in the RF, BF or the MG (see Table 8). No time

effect in the RF, BF or MG (see table 8). No interaction effects were observed in the BF, RF or MG. There was no evidence of any condition effects in any of the muscle groups examined (see table 8).

Table 8. A table showing the f and p-value statistics of the rmsEMG in the RF, BF and MG of the DLT (n=12).

rmsEMG (DLT)			
Muscle	**Condition effect**	**Time effect**	**Interaction effect**
Rectus Femoris	$f_{(1,11)} = .011$, $p = .919$, $\eta p2 = .001$	$f_{(2,22)} = .3.274$, $p = .057$, $\eta p2 = .229$	$f_{(2,20)} = .726$, $p = .495$, $\eta p2 = .062$
Bicep Femoris	$f_{(1,11)} = .058$, $p = .815$, $\eta p2 = .005$	$f_{(2,22)} = 2.129$, $p = .143$, $\eta p2 = .162$	$f_{(2,20)} = .3.845$, $p = .065$, $\eta p2 = .259$
Medial Gastrocnemius	$f_{(1,11)} = .150$, $p = .706$, $\eta p2 = .013$	$f_{(2,22)} = .259$, $p = .774$, $\eta p2 = .023$	$f_{(2,20)} = .691$, $p = .512$, $\eta p2 = .059$

Isometric Lifting Task

In the DLT the mean (±SD) of the rmsEMG in the RF, BF and MG are displayed in table 9 and 10 for IMLT attempt 1,2 and 3 in the control-spray and L-Menthol spray conditions, respectively.

*Table 9. A table showing the mean (±SD) of rmsEMG (v) of IMLT attempts 1, 2, 3 in the RF, BF and MG from the control-spray condition. *indicates where significance occurred (post hoc) when compared to the L-Menthol spray condition, attempt 3 (n=12).*

rmsEMG (v) of IMLT (control-spray)				
Muscle	**Attempt 1**	**Attempt 2**	**Attempt 3**	**Average rmsEMG**
Rectus Femoris	3.00 ± 1.89	4.35 ± 3.20	3.14 ± 1.97	3.49 ± 1.75*
Bicep femoris	4.78 ± 2.35	5.01 ± 2.35	4.65 ± 2.01	4.81 ± 2.20
Medial Gastrocnemius	5.15 ± 2.69	5.43 ± 2.47	5.38 ± 2.98	5.32 ± 2.17

*Table 10. A table showing the mean (±SD) of rmsEMG (v) of IMLT attempts 1, 2, 3 in the RF, BF and MG from the L-Menthol spray condition. *indicates significance when compared to the control-spray conditions, attempt 3 (n=12).*

rmsEMG (v) of IMLT (L-Menthol spray)				
Muscle	**Attempt 1**	**Attempt 2**	**Attempt 3**	**Average rmsEMG**
Rectus Femoris	3.17 ± 1.94	4.96 ± 2.82	4.95 ± 2.17	4.36 ± 1.96*
Bicep femoris	5.05 ± 2.77	5.65 ± 2.98	4.28 ± 2.37	4.99 ± 2.42
Medial Gastrocnemius	4.36 ± 3.12	3.60 ± 2.52	3.86 ± 2.08	3.94 ± 2.31

In contrast to the DLT, there was a significant main condition effect seen (f = 5.450, p = .040) in the RF with rmsEMG being higher in the L-Menthol spray condition than the control-spray condition; condition mean (±SD) were 3.49 ± 1.75 v and 4.36 ± 1.96 v for the control-spray and L-Menthol spray conditions respectively. *Post-hoc* analysis indicated that these differences were primarily generated in the third IMLT repetition which averaged a mean (±SD) of 3.14 ± 1.97 v and 4.95 ± 2.17 v in the control-spray and L-Menthol spray conditions respectively (p = .006). Yet these effects were not evident for either the BF or MG (rmsEMG). Main effects for time were also evident for RF and BF but not MG with rmsEMG generally decreasing over time (see figure 16) in both conditions indicating muscular fatigue. No interaction effects were apparent in any of the muscle groups tested (see table 11).

*Table 11. A table showing the f and p values of the condition, time and interaction in the RF, BF and MG. *indicates significant effect (n=12).*

	IMLT		
Muscle	**Condition effect**	**Time effect**	**Interaction effect**
Rectus Femoris	$f_{(1,11)}$ = 5.450, p = .040*, ηp2 = .331	$f_{(2,22)}$ = 5.135, p = .015*, ηp2 = .318	$f_{(2,22)}$ = 1.136, p = .339, ηp2 = .094
Bicep Femoris	$f_{(1,11)}$ = .070, p = .796, ηp2 = .006	$f_{(2,22)}$ = 4.886, p = .018*, ηp2 = .308	$f_{(2,22)}$ = .991, p = 387, ηp2 = .083
Medial Gastrocnemius	$f_{(1,11)}$ = 1.715, p = .217, ηp2 = .135	$f_{(2,22)}$ = .073, p = .930, ηp2 = .007	$f_{(2,22)}$ = 1.170, p = .329, ηp2 = .096

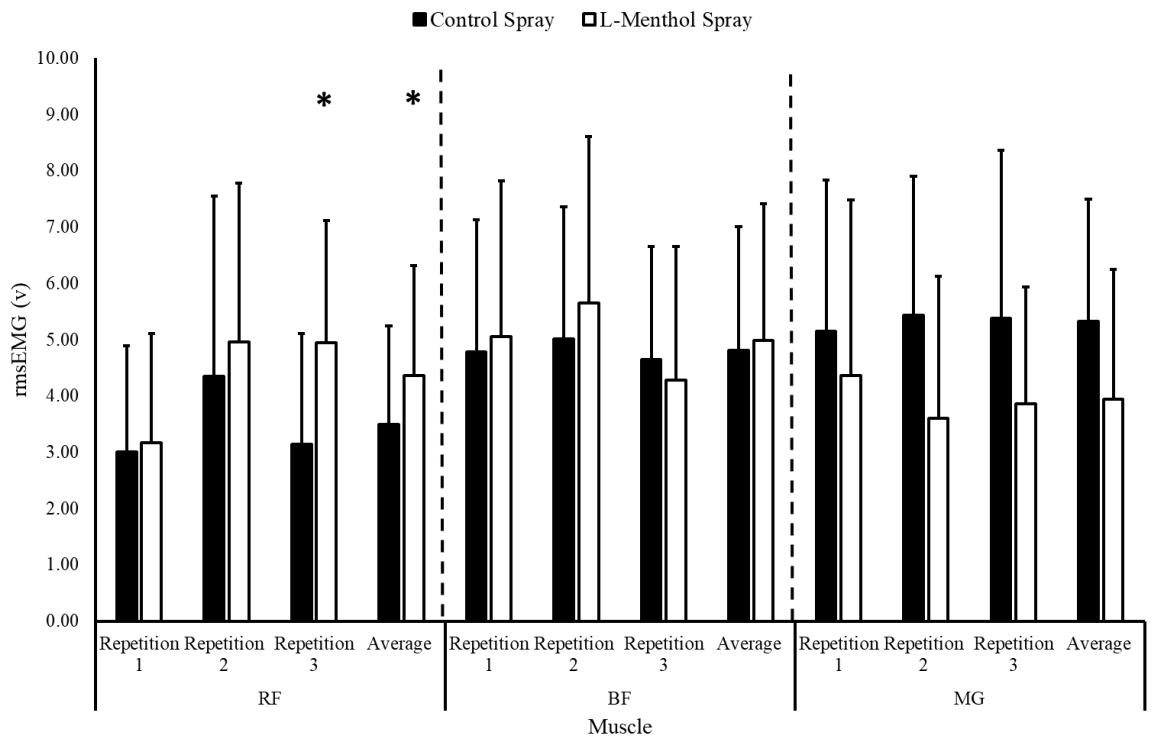

*Figure 16. A bar chart showing the rmsEMG for each repetition in the RF, BF and MG in the control-spray and L-Menthol spray conditions in the IMLT. The bar chart additionally shows the average rmsEMG of each muscle of the control-spray and L-Menthol spray in the IMLT. * indicates the main condition effect (RF), (n=12).*

4.10 Subjective Comments

Subjective comments were taken immediately after the IMLT task was complete in visits two and three (see table 12). This was conducted in a semi-structured interview manner. A variety of comments overall were recorded after the control-spray and L-Menthol spray condition. The trend of the comments showed ten out of the twelve participants stated feeling cooler and colder in the L-Menthol spray condition alongside the trend of feeling the spray lasted longer and post-exercise trial. Two participants reported feeling more comfortable in the L-Menthol spray condition compared to the control-spray condition.

Table 12. A table showing participant subjective comments after visit 2 and 3. CS (control-spray) and MS (L-Menthol spray), (n=12).

Participants	Subjective comments
Participant 1	CS: no comments. MS: "The second spray was cooler instantly, legs still feel cool, cooler than last time"
Participant 2	CS: "felt cool but did not stay as cool as the first time. Not as distracting as first spray" MS: "very cold. I still feel a sensation now" (after the trial ended).
Participant 3	CS: "the spray made me feel more energised" MS: "the spray made me feel more ready to train, more in the mood to do it"
Participant 4	CS: "legs feel cool, nothing like the other spray, legs still feel warm. It was slightly harder this time round lifting". MS: "legs are cooler, feels like deep heat. I am still feeling a slight sensation now".
Participant 5	CS: "legs felt colder, it felt slightly longer for it to hit and felt like a harder 10 reps this time round". MS: "Thought it would help me lift and legs felt cool. I didn't feel any fatigue".
Participant 6	CS: "spray felt wet a slightly cool on legs, I don't think it helped in my lifting". MS: "did not feel as cool although, didn't struggle as much this week compared to last and last week (visit two) felt cooler".
Participant 7	CS: "really cold, I don't think there was any difference in my performance". MS: "More difficult to lift this week because it was too cold – still feeling cold now".
Participant 8	CS: "legs were cool but didn't feel any real sensation. Did not have any aid in lifting I felt. Coolness wore off after 10 reps". MS: "legs felt significantly cooler this week and tingly, I didn't expect my performance to be influenced positively. Still feel cool now. Comfortable to lift with".
Participant 9	CS: "Different to last time, no sensation this time. Did not feel any change in lifting performance. No difference and sensation after testing and slightly fatigued". MS: "It feels cold, like a menthol type of feeling. Tingly like deep freeze. Still feel sensation but wearing off. No difference when lifting".
Participant 10	CS: "A bit cool, compared to the first time where it felt numbing. Did not feel as cold as last time. the smell or feel was nothing like last time (peppermint). My lifting felt roughly the same". MS: "Spray felt cold and chilled. It felt comfortable. Legs feel a bit numb, not over trained. But it feels like deep freeze, like peppermint chewing gum".
Participant 11	CS: "really cold, colder than last week. It was almost uncomfortable. It felt harder to lift today and the spray has worn off, legs feel warm". MS: "It felt Counter-intuitive to warm up because it cooled my legs and still feel relatively cold after exercise. Felt colder throughout the exercises. It didn't feel like it counteracted the deadlifting though".

Participant 12	CS: “pretty cold from the warm-up. I feel slightly warm like it has worn off. Did not feel anything from the spray. Didn’t feel any aid towards lifting performance”. MS: “effects of the intervention are still current, like deep heat *(mentholly).* My body feels the same temperature to touch but legs feel cooler internally. Did not feel it helped with lifting but feel better recovery wise. Feels like I could and would do it all again”.

4.11 Participant Debrief and Blinding

The participant blinding was unsuccessful. Nine participants responded correctly matching the condition to the correct visit. Two participants were unsuccessful at matching the condition to their visits and one participant was *unsure* on the condition blinding (see table 13 and appendix F)

Table 13. A table showing participants response to the blinding protocol (n=12).

	Condition blinding		
Participants	**Correct**	**Incorrect**	**Not sure**
Participant 1	1		
Participant 2		1	
Participant 3	1		
Participant 4	1		
Participant 5			1
Participant 6		1	
Participant 7	1		
Participant 8	1		
Participant 9	1		
Participant 10	1		
Participant 11	1		
Participant 12	1		
Total	9	2	1

Chapter 5

5 Discussion

5.1 Aims and Hypotheses

The present study sought to examine whether an application to the skin of a single low concentration of L-Menthol (0.20%) improved explosive, maximal dynamic and static resistance exercise performance. The data shows an increase in rmsEMG indicating a greater muscular activity response during the IMLT in the RF ($f_{(1,11)} = 5.450$, $p = .040$, $\eta p2 = .331$) after L-Menthol spraying in comparison to the control-spray condition. This was primarily seen in the third repetition (confirmed by a *post-hoc* test) of the IMLT and averaged 3.14 ± 1.97 v and 4.95 ± 2.17 v ($p = .006$) in the control-spray and L-Menthol spray, respectively. Furthermore, the rmsEMG was higher in the L-Menthol spray than the control-spray condition across all three maximal attempts and averaged 3.49 ± 1.75 v and 4.36 ± 1.96 v in the control-spray and L-Menthol spray conditions, respectively. However, there was not a statistical performance improvement when comparing both control and L-Menthol spray conditions as a similar force was produced in the third repetition of the IMLT in both conditions where the main condition effect was observed (140.0 ± 26.0 KGF and 139.6 ± 27.1 KGF) respectively. The average weight pulled (KGF) across all three attempts in the control and L-Menthol conditions also saw no statistical performance improvement (138.7 ± 25.4 and 141.1 ± 29.2), respectively. In addition, in the rmsEMG and force produced in the L-Menthol condition, it was seen on average 67% (8 out of the 12; the mean (±SD) improvement in these 8 participants was 151 ± 30 KGF showing a 15 KGF difference compared to the control-spray condition average; 136 ± 16.5 KGF) of participants were able to produce more force in the L-Menthol spray condition when comparing to the control-spray condition in the IMLT, but again, this was not statistically different. Although the average force produced across all three maximal isometric lifts is numerically higher in the L-Menthol spray condition compared to the control-

spray, it is an interesting notion to see whether there could be a potential statistical improvement in performance with L-Menthol application in future research. With previous literature showing a relationship between rmsEMG and RFD (Shimose et al, 2014), the present study cannot relate as there was no significant difference in performance even though increased rmsEMG was evident. However, it is evident L-Menthol spray application altered neuromuscular activity peripherally due to the increased rmsEMG. It is therefore concluded, H_2 can be partially accepted as EMG was altered but statistically did not improve lifting exercise performance or allow more weight to be lifted.

It was also suggested that sprayed application of L-Menthol to the legs would improve weightlifting performance, allow participants to lift more and lower RPE. Our results show RPE was not different between the control-spray and L-Menthol spray conditions in the DLT. The RPE during the IMLT followed similarly showing no statistical difference between control-spray and L-Menthol spray. There was a significant time effect seen in the IMLT, with data indicating an increase in RPE over time. However, the significant effect on time is unremarkable, as this variable is commonly expected to change over time significantly. Participants also completed ten repetitions in each visit (control-spray and L-Menthol spray) of the DLT where RPE was unchanged. Therefore, H_1 is rejected. An additional key finding was the statistical and subjective difference in TS_{legs} in the IMLT. This difference was in the L-Menthol spray condition, and subjectively participants stated their legs felt cooler. A statistical and subjective difference was also seen in participants TC_{wb}, meaning participants felt more comfortable in the L-Menthol spray condition than the control-spray condition in the IMLT and subjectively felt more comfortable prior to the DLT in the L-Menthol spray condition.

5.2 Novel findings

5.2.1 Root Mean Squared Electromyography

To our knowledge, this is the first study conducted to investigate and examine the effects of L-Menthol on maximal static and dynamic resistance exercise performance using a single application of L-Menthol spray. The key novel finding of this study was the significant main condition effect of rmsEMG seen in the L-Menthol spray condition in the IMLT in the RF. In the initial literature review, we had suggested the mechanism of peripheral muscular facilitation via the sensory-somatic pathways could be a plausible mechanism by which an L-Menthol application could act upon and potentially affect dynamic and static muscular movements. Our results potentially share a similar relationship of that shown by Shimose and colleagues (2014), who studied the effects of SC on the quadricep muscles. It was seen in the study conducted by Shimose and colleagues (2014), there were significant increases of rmsEMG and RFD in the vastus medialis, vastus lateralis and rectus femoris in the early stages of contractions of maximal low load isometric knee exercise. It was concluded, their results supported that SC increased neuromuscular drive in the working muscles via skin receptors, stating, especially cold receptors of the skin. We believe, a similar mechanism could be evident in our own study to that of Shimose and colleague (2014) and possibly Tokunaga and colleagues (2017), who saw a 35% increase in MVC at a low load using menthol gel on the quadriceps muscles. In the present study, we also contend that the application of L-Menthol to the skin has stimulated cutaneous thermoreceptors within the PNS which has induced cool sensations much like actual skin cooling and activated the TRPM8 ion channel. The sensory-somatic neural pathway transmits this information in the form of electrical signals which conducts through to the CNS (Thomas et al, 2000; Kayser, 2003). The CNS produces electrical signals in the form of action potentials. As TRPM8 acts similarly to other Lingard gated channels (Chuang, Neuhausser & Julius, 2004), this allows rapid influx of action potentials to travel through the MN of the

working muscle and excite the MU's as the muscles begin to contract. This would explain the increase in rmsEMG in the present study on the RF in the L-Menthol condition which was significantly different to the control-spray condition of the IMTP. This has been supported by previous literature, and it has been stated literature supports the mechanism which TRPM8 sensory input is responsible for skin cooling mediated MN excitability (Tamura, 2019). Furthermore, there was a decrease in T_{skin} measurements, as SC decreased T_{skin} to 24°C (Shimose et al, 2014). In the present study, T_{skin} was measured and showed the average skin temperature dropped in both conditions and plateaued after 6 minutes and was 27.7 ± 1.20 °C and 27.8 ± 1.20 °C in the control-spray and L-Menthol spray conditions, respectively and was not shown to be different between conditions. In addition, even though there was visual evidence of a lowered T_{skin} shown from the AUC in the L-Menthol spray condition, it was not statistically different. However, Shimose and colleagues (2014) did not examine L-Menthol application and we believe the significant increases of rmsEMG in the RF in the present study, during maximal isometric exercise, was induced by a similar mechanism. It was mentioned by Shimose and colleagues (2014) neural drive was affected by particularly cold skin receptors. We believe in the present study, the L-Menthol spray stimulated the TRPM8 ion channel previously mentioned as being chemically activated by L-Menthol which has induced action-potential in the muscle via an increase of calcium ions which have increased the excitability of MN's and increased MU recruitment which was shown by the rmsEMG. It is also believed with the activation of TRPM8 via the L-Menthol spray, it chemically altered and induced neuromuscular changes without significantly altering T_{skin}. This ultimately induced greater rmsEMG of the RF significantly through TRPM8, via the PNS inducing peripheral muscular facilitation and chemically altered the CNS to believe the body was cooling without altering T_{skin}.

5.2.2 Thermal perceptions

A second novel finding from our study is the significant difference between participants thermal perception of TS_{legs}, in the L-Menthol spray condition compared to the control-spray condition. To our knowledge, this is the first study to specifically examine thermal perceptions in the legs during this type of physical activity. Participants perceived their legs to be cooler with the application of L-Menthol spray than the control-spray in the IMLT. The study by Schlader and colleagues (2011) found indications of thermal perceptions and T_{skin} can be uncoupled by the chemical stimulation of L-Menthol as facial T_{skin} showed no significant differences between capsaicin, control or the L-Menthol conditions, but saw a significant difference in facial temperature in the thermally heated and cooling conditions. It was also evident L-Menthol application saw the greatest amount of work completed compared to all conditions. The uncoupling of thermal perceptions from T_{skin} is evident from Schlader and colleagues (2011) additional study which explored T_{skin} and the potential role it plays on self-selected exercise intensity. At the start of exercising, T_{skin} was numerically different showing participants were cooler in the C to H condition which caused participants to perceive their TS as cooler and perceived increased thermal comfort when exercising at a cooler starting temperature compared to a starting hot temperature. Therefore, with a lower initial T_{skin}, the lower participants TS and TC perceptions were, in which saw a greater work and greater power output completed when participants started at a cooler temperature. In comparison to the findings of the present study, T_{skin} did not see any significant reductions, even though average T_{skin} did initially drop following the initial spraying, T_{skin} plateaued for the duration of the experimental trial. We believe the L-Menthol spray application chemically stimulated TRPM8 which is why participants felt significantly cooler in their legs and felt greater comfort of their whole body. The results are similar to that of Barwood and colleagues (2015) which found

significant differences in TS after spraying of L-Menthol at the 10 km mark, for which after participants felt significantly cooler at the 12, 14 and 16 km TT mark. Participants also perceived greater comfort at the 12 and 16 km TT mark. Barwood and colleagues (2015) T_{skin} results are also similar, which saw a dip in T_{skin} in both spraying conditions, however, these were not significant. This indicates L-Menthol was chemically uncoupling thermal perceptions from T_{skin} when it was applied after the 10 km mark. The evidence from previous literature suggests T_{skin} should not be different as L-Menthol stimulates the skin in the absence of a comparable change in temperature via TRPM8 chemically. However, the results of the AUC in the present study shows a trend in the direction of L-Menthol influencing T_{skin} as it is visually lower than the control-spray condition (not statistical). The potential reason for this is, vasoconstriction may have occurred when the L-Menthol was present, effectively reducing T_{skin} slightly (Barwood et al., 2015). It has been known that TRPM8 activation can initiate vasoconstriction, which reduces blood flow and heat to the skin Johnson and colleagues (2009) therefore reducing T_{skin}. However, due to the unique nature of our study, there is limited to no research conducted on thermal perceptions on maximal isometric lifting at ecologically valid environmental conditions, therefore it is hard to determine whether vasoconstriction did occur. The studies which have been mentioned in the present thesis have been conducted in hot and humid environments and the studies such as Shimose and colleagues (2014) and Tokunaga and colleagues (2017) did conduct in ecologically valid, temperate conditions, however, Shimose and colleagues did not use L-Menthol application on maximal performance and Tokunaga and colleagues (2017) also did not conduct L-Menthol gel on maximal performance and was aged related. Therefore, it is interesting and novel to note participants in the present study perceptually felt cooler in their legs and felt more comfortable (whole-body) when environmental conditions were statistically not different between conditions and were not modified to be hot or cold. Furthermore, the spray solution itself was set just above average

T_{skin} and was not different between conditions. This was to ensure it was only the L-Menthol that could potentially affect thermal perceptions. Taking into consideration the tendency seen from previous studies of an uncoupling effect of thermal perception from T_{skin}, the results of the present study can associate with this previous literature, as the results in the present study of T_{skin} were not statistically different, and participants perceived to be significantly cooler and perceive greater comfort with the application of L-Menthol spray in the IMLT, therefore, showing L-Menthol at temperate conditions has the potential to uncouple thermal perceptions from T_{skin}. This suggests promise to a wider application of L-Menthol, however, further research needs to be conducted in the area of strength and exercise performance.

To further add, another interesting finding which potentially may relate to the explanation of the significance of TS_{legs} in the IMLT is a study conducted by Lee, Nakao, Bakri and Tochihara (2012) studied the effect of 0.8% L-Menthol application on eight regions of the body compared to a non-L-Menthol condition on thermal body regional influences. The results of the experiment showed L-Menthol application evoked earlier detection of cool sensations in seven out of the eight body regions which included the thigh and calf regions. Their data indicated the legs (thigh and calf) were thermally more sensitive to L-Menthol. Furthermore, in relation to a higher TS_{legs} in the IMLT, participants perceived to be more comfortable in the L-Menthol spray condition than the control-spray condition, as TC_{wb} showed a significant difference in the IMLT and subjectively started to feel more comfortable prior to the DLT (not statistically) with the application of L-Menthol. In the same study of Barwood and colleagues (2014), participants perceived being increasingly more comfortable with the application of L-Menthol compared to the control condition. However, it is interesting to see no improvement in performance even though participants felt cooler in their legs and felt more comfortable (whole-body) prior to the IMLT in the L-Menthol spray condition, as an individual's perceived comfort of their body temperature compared to their actual body temperature, could potentially

be more performance influencing during exercise in the heat (Schlader et al, 2011). This offers up an interesting point into more research to be conducted, as even though participants in the present study felt more comfortable and were not in heated conditions, there was still no significant exercise performance improvement. This suggests thermal perceptions can be still altered and improved in temperate conditions; however, more research should be considered to study L-Menthol application on maximal strength-based performance activities. Although, since there has been evidence of performance improvement in the heat in endurance exercise (Barwood et al, 2019), SC increased rmsEMG and RFD (Shimose et al, 2014) and the present study has shown L-Menthol spray application increased rmsEMG in the RF and induced neuromuscular activity in maximal static performance, this could give reason to test L-Menthol spray application on maximal strength performance in warm and humid climates to see if whether an application of L-Menthol can statistically improve maximal strength performance. as weightlifting events in warmer climates, such as the Tokyo Olympics in 2020 are scheduled to take place.

5.3 Exercise Performance

It is interesting to see exercise performance was unchanged, even though statistical differences were seen in our two key novel findings of the present study in the L-Menthol spray condition which have been seen to be drivers of improving exercise performance. In the study conducted by Shimose and colleagues (2014), they showed that SC of the quadricep muscles improved RFD and along with an increased rmsEMG indicating increased neuromuscular drive. In comparison to the present study, it was seen rmsEMG was significantly increased compared to the control-spray in the RF in the IMLT, however, it is interesting to see no improvement in performance as a result of increased rmsEMG, due to being strongly related to increased RFD. Alternatively, the study conducted by Tokunaga and colleagues (2017) saw again, significant increases in rmsEMG in the vastus lateralis and vastus medialis muscles in the quadricep,

between adult L-Menthol and older adult L-Menthol, however, they saw a significant decrease in mean power frequency in older adult L-Menthol but not adult L-Menthol. This study was age focused, however, in terms of not seeing decreases in mean power frequency in the adult L-Menthol group, our results follow the trend seen here, as our results saw no significant reductions or improvement in the performance of a similar age-related group. Although, it is evident that increases in rmsEMG and decreases in MPF are due to the onset of fatigue and the synchronisation of the firing of MU's (Krogh-Lund & Jørgensen 1991; Krogh-Lund & Jørgensen 1993). Since the nature of the protocol in the present study of the IMLT which consisted of performing maximally for 3-seconds, and resting for 90-seconds, the onset of fatigue may have occurred, possibly due to a short rest period which was not entirely sufficient enough to recover from three seconds of maximal contractions. The third repetition of the IMLT, as described above in the results section of this thesis, was where the main condition effect of rmsEMG was seen in the RF with the application of L-Menthol spray, which was the last repetition of the IMLT. Therefore, it is more likely the onset of fatigue may have affected performance. However, the force produced was similar to the force produced in the control-spray condition, despite the forces produced in the first and second repetition in the L-Menthol spray condition were numerically higher compared to the control-spray condition. Therefore, it may be possible that L-Menthol combats the onset of neuromuscular fatigue, due to TRPM8 activation, which has seen to increase the excitability of MN's and increase MU recruitment to produce greater force. It is also interesting to see no improvement in performance as participants perceived to be cooler and perceived increased comfort during the IMLT. It was shown by Schlader and colleagues (2011) which investigated temperature and thermal perception as potential controllers of thermoregulatory behaviour. Participants felt significantly cooler (whole body TS) compared to the heating conditions and at stages, significantly feeling more comfortable (whole body TC) with L-Menthol application. This resulted in a greater work

completed in the L-Menthol conditions compared to the thermal heating and capsaicin conditions. In comparison to our findings, even though participants perceived to be cooler in their legs and felt greater whole-body comfort in the IMLT, thermal perception was not seen to control thermoregulatory behaviour like it was seen by Schlader and colleagues (2011). However, the nature of the tasks were different (endurance and maximal strength performance).

5.4 Rating of Perceived Exertion, Heart Rate and Readiness to Train

HR was included in the research for exploratory purposes. It showed there were no significant differences between the conditions of HR. However, it is interesting to discuss, peripheral vascular constriction can be induced by direct effects of cooling (Lewis & Landis 1930). With this being said, Johnson and colleagues (2009) suggested, TRPM8 activation has been shown to initiate vasoconstriction. In addition, it was concluded by Gillis and colleagues (2010) that a 0.20% L-Menthol concentration evoked vasoconstriction by comparable means to cold stimuli to the skin, which overall reduces blood flow and heat loss at the skin. We cannot conclude L-Menthol had this effect in the present study on HR. RTT was also included in the research for exploratory purposes as this is the first time it has been used to our knowledge in relation to L-Menthol application on exercise performance. There was no difference in RTT between conditions.

In relation to RPE, this was not just measured for exploratory purposes, as this was expected to be lower in the present study between conditions, as this relates to our $H_{1.}$ We hypothesised RPE would be lower in the L-Menthol spray condition. However, it was not lower, and no differences were seen between conditions. Interestingly, Barwood and colleagues (2015) saw a significant reduction in RPE in cyclists after L-Menthol spray had been applied compared to a control. However, this did not result in increased self-selected power output. Barwood and colleagues (2015) suggested RPE changes would need to be of greater magnitude to see any

changes in power output. Our results do not see a similar reduction in RPE with L-Menthol spray application, as the results did not show any reductions in RPE after the DLT or during the IMLT. RPE did show a significant effect over time in the IMLT, although, this time effect was showing an increase of RPE over time in both conditions. With that being said, it is suggested there is a linear relationship between HR and RPE, as Noble and colleagues (1983) in there study of the Borg scale (Borg, 1982) on HR, blood and muscle lactate during a progressive maximal exercise test, which saw HR increase linearly with RPE. However, in the present study, there was no evidence of a significant time effect in HR. There was a slight increase in the average HR in the DLT in the L-Menthol spray condition, however, this increase was by 3 $b.p.m^{-1}$. In conclusion, the results of the present study potentially indicate that RPE may have been the main driver of exercise intensity more so than thermal perceptions. As Schlader and colleagues (2011) showed greater work was achieved when perceptions of TS_{wb} were cooler when TC_{wb} was perceived as greater comfort and RPE was set at a fixed intensity. The present study saw participants perceive significantly lower TS_{legs} and TC_{wb} in the IMLT, but this did not stop RPE increasing over time and did not alter or allow for more force to be produced or perceive exercise to be easier in maximal static and dynamic exercise performance.

5.5 Strengths

To summarise the study, there are several strengths which potentially increase the reliability and validity of the present study. To start, the present study, to our knowledge is the first of its kind, with no other study in sporting literature investigating the application of L-Menthol on maximal static and dynamic exercise performance. The present study is also the first to show novel findings on the effects of L-Menthol spray application on rmsEMG on maximal isometric performance exercise and in TS_{legs}, as this study was the first to investigate specific spraying of the legs. The study conducted had a rigorous experimental design, as it was a double-blind, within-subject, repeated measures design. With the study being double-blinded, this decreased

the chance of possible bias from the researcher and participants and reduced the chance of experimental effects occurring. The experimental design used an ecologically valid protocol, which relates to sporting performance, for example, participants were exercise resistance-trained and had at least 12 months prior weight-lifting experience. Environmental conditions as previously mentioned above, were not modified, not statistically different between conditions and at temperate conditions with the exercises performed being well known and studied manoeuvres. To further add, a valid control was used for the control-spray condition, as this contained identical ingredients as the L-Menthol spray, except it did not contain L-Menthol. Therefore, the only difference between both interventions was chemical L-Menthol.

5.6 Limitations

The present study is not without limitation. The required sample size to see a difference in the current study in IMLT lifting performance was estimated based on the experimental effects seen in related research using menthol application (Barwood et al, 2019). The result suggested nine participants would need to be tested to see a significant difference; 12 were recruited to account for participant attrition. This calculation was performed prior to undertaking data collection. A post-hoc power calculation using the current data indicates that approximately 813 participants would need to be tested to see a significant difference based on the current mean (±SD) differences between the test conditions; G*Power, version 3.1, University of Dusseldorf, Germany; difference between conditions 2.4, ±SD 13.7 KGF; power 0.80 (see table 14). Clearly this post-hoc estimated sample size is not practically feasible to recruit and test and would only generate a modest (0.08) effect size. Evidently, the transferability of the magnitude of experimental effects from endurance exercise (Barwood et al, 2019) to dynamic and static lifting performance (i.e. the current study) is not proportional. Yet, the current study did select a performance test that has a high-test re-test reliability (i.e. correlation coefficient of 0.89; Comfort et al, 2015) in the type of participants that were recruited here (i.e. trained).

Therefore, at the point of conception, the current study maximised the chances of seeing a performance difference based on the information available at the time.

*Table 14. A table showing the post-hoc G*power output calculation*

G*Power Output	
Noncentrality parameter δ	2.49
Critical t	1.65
Df	812
Total sample size	813
Actual power	0.800

We decided to test males only and not females. Several reasons contribute to this decision, however, by not using females, our results only can be generalised to a male population accustomed to maximal resistance exercise. The blinding was not maintained throughout the experiment. Indeed, 75% of participants were able to connect which visit was L-Menthol spray and which visit was the control-spray (after discovering in the debrief the intervention was L-Menthol). Although only two participants described the feeling of the L-Menthol spray in the semi-structured interview using the word *menthol,* others related the feeling of the L-Menthol spray to peppermint chewing gum and deep heat. Therefore, even though blinding was not maintained, a large majority of participants did not specifically know it was the chemical L-Menthol being applied to their legs. The maximum weight of the bar could have been a potentially limiting factor as the hexagonal bar could only be loaded with a specific maximum amount of weight of 177.2 kg. This was due to the hexagonal bar being small in size. However, there was only one participant that exceeded the total weight load, and this was controlled by attaching two small 2.5 kg plates on each side of the bar and securing the 2.5 kg plates with exercise resistance bands, which held the plates firmly in place. The participant was able to reach their 5RM with this, however, if more weight were needed, this would not have been possible. In addition, the nature of the task performed could be a limitation, as we could not test 1RM, and therefore could not test maximal lifting dynamically. Furthermore, a major

limitation was not being able to use the force plate originally planned, as it broke at the start of pilot testing. This eliminated certain variables we originally planned to test, such as the RFD and a higher resolution of muscular activity, power, and velocity. However, a strength-back dynamometer, measured in KGF, which is used to calculate Newton force was thought as an alternative to measure the force produced by maximal isometric exercise. Participant adherence is a limitation to the present study. Participants were told prior experimental trials to not participate in certain activities, such as the consumption of alcohol and avoid heavy strenuous exercise 24hrs prior to testing and not to consume caffeine 8hrs prior to testing. This could only be controlled up to an extent. In addition, during the EMG electrode application, it was explained participants used a permanent marker system to maintain the clarity of where the EMG electrode was to be placed in visits two and three. This was generally well maintained, and participants did their best to adhere to the procedure. The final limitation of the present study, to our knowledge was applying the L-Menthol to the whole muscle. The EMG electrode or the adhesive strip was not water-resistant, therefore, the calculated anatomical location of the muscle where surface EMG needed to be measured, needed protecting so the adhesive strip could hold the electrode on the muscle during exercise for up to 25-minutes. This meant, during spraying, this specific area of the muscle, is thought not to have had direct contact with the L-Menthol spray.

5.7 Future Directions

The results from the present study, indicate further research should be conducted with L-Menthol on maximal static and dynamic exercise performance. There are several future directions which should be explored to enhance and build upon the knowledge attained from the present study. Firstly, a repeated application of L-Menthol spray could be used and possibly a higher concentration of L-Menthol, which could potentially aid to a statistical difference in performance. Depending on the extent of performance improvement, L-Menthol application

could be classed as an ergogenic aid to maximal static and dynamic movements. Barwood and colleagues (2019) stated repeated L-Menthol spray application is ergogenic in trained participants during cycling in hot conditions, which used a 0.20% L-Menthol concentration. In addition, Gillis and colleagues (2010) concluded 0.20% L-Menthol application improved upper body TS which did not see any influence on mean T_{skin} but saw no effect on thermal comfort. Unlike the present study which did see a difference in TC_{wb}. Furthermore, Tokunaga and colleagues (2017) saw significant increases in rmsEMG with the application of a 5% concentrated L-Menthol gel pad. Therefore, more research needs to be conducted to see if there is a potential optimal concentration of L-Menthol. In addition, as it was previously mentioned in the above discussion, maximal static and dynamic performance should potentially be conducted to warm and humid environments to see if there would be an improvement in performance. This could potentially be interesting to sporting literature as weightlifting events which occur in warmer and more humid climates could be a potentially limiting factor to performance which L-Menthol application could potentially aid.

Repeated or extended IMLT's is a possible avenue to explore, as our results show significant increases in rmsEMG with an L-Menthol spray application over a 3-second IMLT which was repeated three times. If the task had an extended duration or increased repetitions, there may be a possibility to see statistical improvement in performance with the application of L-Menthol over time and possibly a reduced RPE. In relation, extending repetitions to more than ten in the DLT should be explored, as, from our results, there was no difference in performance as all twelve participants lifted ten repetitions. This indicates to either extend the repetitions, to see if L-Menthol spray application could have a performance-enhancing effect or conducted a 1RM procedure of a DLT. Finally, from the results of previous literature and of the present study, L-Menthol application should eventually be explored in possible training capabilities as it may enhance overall performance in the long-term. The present study shows an early indication of

the possibility that L-Menthol could be performance-enhancing in maximal isometric weightlifting in resistance-trained participants. The isometric mid-thigh pull is commonly adopted as a manoeuvre to examine peak forces and isometric strength which are said to be critically important to improve overall strength performance. In relation to improving performance, a study conducted by Pierce, Rozenek and Stone (1993), studied the response of HR and RPE to high volumes of resistance exercise and a weight training program over eight weeks. The results showed significant reductions in HR and significant decreases in RPE, with which the authors concluded, that an 8-week high-volume weight training program can reduce HR and RPE which potentially may enhance an individual's ability to endure increased sets of resistance exercise, emphasizing of large muscle groups. In conclusion, if more research is to be conducted, it would be interesting to see the effect L-Menthol application on maximal isometric and dynamic resistance exercise employing the recommendations above.

5.8 Conclusion

To summarise, the present findings include novel contributions to the sporting literature and adds to the growing literature of L-Menthol as an intervention in sport. In the present study, it is seen that a single 0.20% L-Menthol spray application to the legs significantly increases rmsEMG in the RF during a maximal IMLT and has also shown to significantly lower TS_{legs} and increase TC_{wb} during the IMLT. However, this did not improve maximal static or dynamic resistance exercise performance. It is believed, the L-Menthol spray application stimulated the TRMP8 ion channel which in turn activated peripheral muscular facilitation which excited the activity of MN's, which influenced neuromuscular modulation in the RF during maximal isometric exercise performance.

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Appendices

Appendix A – Participant Health Questionnaire screening form (PAR-Q)

Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people, physical activity should not post any problems or hazards. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.
Common sense is your best guide in answering these few questions. Please read the statements carefully and circle YES or NO opposite the question if it applies to you.

Has your doctor ever say you have heart trouble? *If YES, please explain:*	YES	NO
Do you frequently have pains in your heart or chest? *If YES, please explain:*	YES	NO
Do you often feel faint or have spells of severe dizziness? *If YES, please explain:*	YES	NO
Has a doctor ever said your blood pressure was too high? *If YES, please explain:*	YES	NO
Has your doctor ever told you that you have a bone or joint problem(s) (e.g. arthritis) that has been aggravated by exercise, or might be made worse with exercise? *If YES, please explain:*	YES	NO
Is there a good physical reason, not mentioned here, why you should not follow an activity program even if you wanted to? *If YES, please explain:*	YES	NO
Are you or have you been pregnant in the last 6 months?	YES	NO
Do you suffer from any problems of the lower back (i.e. chronic pain, numbness)? *If YES, please explain:*	YES	NO
Are you currently taking any medications? *If YES, please explain:*	YES	NO
Do you currently have a disability or a communicable disease? *If YES, please explain:*	YES	NO
Do you suffer from any allergies including food and/or skin? *If YES, please explain:*	YES	NO

Has your doctor, or other health professional, told you not to undertake any physical activity?	YES	NO

If you answered NO to all questions above, it gives a general indication that you may participate in physical activity and aerobic fitness activities. The fact that you answered NO to the above questions is no guarantee that you will have a normal response to exercise. If you answered YES to any of the above questions, then you may need written permission from a physician before participating in physical and aerobic fitness activities.

_____	_____	____ / ____ / _____
PRINT NAME	*SIGNATURE*	*DATE*

PARTICIPANT INFORMATION SHEET

Principal Investigator: Mr Daniel Over
Telephone: 07584 902671
Email: 1400571@leedstrinity.ac.uk

Department of Sport, Health and Nutrition

Brownberrie Lane, Horsforth,
North Yorkshire, LS18 5HD

If Principal Investigator is a student:
Supervisor: Dr Martin Barwood
Telephone: 0113 283 7100 ext 285
Email: m.barwood@leedstrinity.ac.uk

STUDY ONE TITLE: The effect of surface body sprays on maximal and dynamic weightlifting performance

We would like to invite you to take part in our research study. Before you decide we would like you to understand why the research is being done and what it would involve for you. Please ask us if there is anything that is not clear.

We are looking to recruit males, aged between 18 and 40 years old (inclusive) who are experienced in resistance training exercise; i.e. you have been resistance training for 12 months or more for 3 times a week or more. To be eligible you must be accustomed to maximal lifting and familiar with undertaking a “deadlift” and “mid-thigh pull” weightlifting manoeuvre and complete our health screening form and complete a blood pressure check. We require participants who do not suffer from any food or skin allergies.

What is the purpose of the study?
The purpose of the study is to examine whether two different types of surface body spray can influence your weightlifting performance.

Why have I been invited?
You have been invited to take part because you fit the eligibility demographic and may be motivated to contribute to the research.

Do I have to take part?
Taking part in this research is entirely voluntary. It is up to you to decide if you want to volunteer for the study. We will describe the study in this information sheet. If you agree to take part, we will then ask you to sign the attached consent form.

What will happen to me if I take part?

If you choose to take part, we will ask you to visit the strength and conditioning (S & C) suite on three separate occasions for approximately 1 hour on each visit. We will ask you to visit at similar times of day with 5 to 7 days between visits. On each occasion, following your arrival, we will ask you to complete a standardised warm-up

by cycling at a low intensity on a static bike for 5-minutes. We will also ask you to complete self-selected dynamic and static stretches of the muscles you will use for lifting. Lastly, we ask you to commence each activity with a series of sub-maximal lifts. Lifting performance will be supervised by a qualified trainer on the first visit with a first aider on hand within the building.

Visit One: The primary aim of visit one is to establish your predicted one repetition maximum (1RM) lifting capability while performing the deadlift lifting manoeuvre. We will also be looking to establish what your normal performance level is in a maximal isometric lift with the bar held in a fixed position. Prior to undertaking these activities, and after completing the warm-up, you will be asked to sit down during which time we will explain some of the perceptual scales we will use during the study to document how you feel throughout each visit. In visit one, these will describe your level of exertion (Rating of Perceived Exertion; RPE) and your “readiness to train” (RTT). We will ask for these ratings at set intervals during the study. We will ask you to put on a heart rate monitor and will attach some sensors to your legs at your calf, thigh, hamstring and on your kneecap, which will measure your muscle activity during each lift. The placement of the sensors may require us to prepare the area where the sensor will be located by cleaning and shaving a small section of your skin (i.e. 2 to 3 square centimetres in each location). Please let us know if you have any allergies to alcohol gel and shaving foam.

For reasons of safety and risk, we are not asking participants to complete a 1RM deadlift. Instead, we are predicting this value by asking participants to undertake a 5 repetition (5RM) maximum protocol from which 1RM can be predicted. We will firstly ask for your estimation of what you think you will be able to lift for 5RM. We will then load the bar with 75% of this estimate and ask you to complete 5 deadlifts of this value with one repetition every 10-seconds. You will then be asked your RPE rating, complete a 3-minute rest and then attempt 85% of this maximum. This pattern will continue with 95%, 100% and 101 to 110% of your estimate added each time; the final increment will be based on how easily you lift the preceding weight. You will complete a maximum 5 increments. We can mathematically predict your 1RM from your 5RM performance and this value will be used to decide upon a maximum weight you could lift for 10-repetitions as part of a dynamic lifting task (DLT). The dynamic lifting task will be practised at the end of this visit and will be a key performance indicator in this study. You will then complete a 5-minute rest period and prepare for the isometric maximal lifting task (IMLT).

The IMLT measures your ability to generate force when your muscle is in a fixed position and is lower risk than using free weights as the bar is held in a fixed position and cannot be dropped. This is a maximal activity and requires you to stand on a platform and pull up against a bar held in a position approximately at your mid-thigh. We can measure your performance in the task by having you perform the activity on a force platform which measures the force that is generated underneath you. Firstly, we will check your positioning relative to the bar and you will complete three short (1-second) efforts at 25%,50% and 75% effort level with a brief rest. We will then ask you to complete three 3-second maximal efforts with 90-seconds in between. You will now have another short rest period of the 3-minutes following which you will return to the deadlift activity and practice the DLT by completing five repetitions of your predicted load. In visits two and three the DLT will comprise 10 repetitions at this calculated

weight. Lastly, we will invite you to complete a standardised cool down procedure by cycling at a low intensity on a static bike and completing self-selected dynamic and static stretches.

Visits two and three: You will be asked to prepare in the same manner as visit one. A qualified trainer and first aider will be available for consultation throughout visits two and three. During these visits, you will complete the DLT and IMLT. The DLT which requires you to complete 10 repetitions of a deadlift at 75% of your 1RM which was established on visit one. After the warmup and during the preparatory period we will apply 100 mL of one of two spray solutions to your legs. These sprays are similar to commercially available body sprays and have been prepared by an independent organisation (i.e. Chemical Associates, Frodsham, Cheshire). They have been used previously on multiple occasions at the concentrations used in the present study in exercise sciences research without any adverse effect having followed the participant screening outlined above. In addition to RPE and RTT, we will ask you to report your perceptions of thermal sensation (TS; how hot, cold or neutral you feel) and your thermal comfort (TC; how pleasant it feels to be at that temperature). We will also attach some sensors to your skin to measure your skin temperature during the trial. The IMLT will be identical to the procedure described above with the same cooldown procedures to follow.

Expenses and payments
There are no expenses. However, this study will provide helpful performance feedback on your weightlifting capability from a qualified trainer.

Anything else I will have to do?

On each occasion, please bring the same clothing which should be suitable to undertake resistance exercises; e.g. shorts, sweatshirt/t-shirt, socks and flat, lace-up shoes. Please be aware that shorts are essential as we will need to attach sensors to your legs during each visit. Please avoid maximal exercise and alcohol consumption on the day preceding each visit and abstain from caffeine in the 8 hours preceding the trial.

What are the possible disadvantages and risks of taking part?

There are some minor disadvantages to taking part and these include a small commitment of your time and effort. Weightlifting includes the risk of injury through incorrect technique and slips, trips and falls. You may also feel some muscular soreness in the days following each visit.

These risks have been reduced by ensuring a warm-up to maximal lifting is included as standard and you will be free to stretch before each effort. You will also be asked to complete a series of sub-maximal efforts prior to maximal lifting. A qualified trainer and first aider will be available to ensure correct technique is used during your first visit for each lift. The soreness you experience post-exercise will decline approximately 48 hours after each visit. Lastly, your participation will enable us to give some detailed performance feedback on your weightlifting capability as compensation for your time and effort commitment.

What are the possible benefits of taking part?
In addition to the benefits of completing exercise, which is good for your health, you may be contributing to identifying an effective means of enhancing resistance exercise performance which could be of interest to the exercise community.

Will my taking part in the study be kept confidential?

Your participation and information specific to you will be kept confidential. The raw data, which identifies you, will be kept securely by the Principal Investigator and/or the Supervisor in a locked office when not in use by the researchers. Electronic data generated from the study will be stored on the University's secure server on password-protected computers in accordance with institutional data protection policy (i.e. GDPR).

When reporting the data as part of the research process your data will be made pseudonymous by allocating a specific code that relates to you. Only the research team will know the code, and this will not be stored with the main project data. The data, when made pseudonymous, may be presented to others at scientific meetings, or published as a project report, academic dissertation or scientific paper or book. Anonymous data, which does not identify you, may be used in future research studies approved by an Appropriate Research Ethics Committee.

The raw data, which would identify you, will not be passed to anyone outside the study team without your express written permission. The exception to this will be any regulatory authority that may have the legal right to access the data for the purposes of conducting an investigation in exceptional cases.

The raw data will be retained for 6 years. When it is no longer required, the data will be disposed of securely (*e.g.* electronic media and paper records/images) and destroyed.

What will happen if I don't want to carry on with the study?
As a volunteer, you can stop any test at any time, or withdraw from the study at any time before finishing all experiments, without giving a reason if you do not wish to. If you do withdraw from a study after some data has been collected, you will be asked if you are content for the data collected thus far to be retained and included in the study. If you prefer, the data collected can be destroyed and not included in the study; you will have a 14-day period after your completion of the study to withdraw. If you choose to withdraw then please email the project supervisor or, if you would rather, contact the chair of the ethics committee (details below).

What if there is a problem?
If you have a concern about any aspect of this study, you should speak to the Principal Investigator in the first instance if this is appropriate, or the Supervisor (both detailed below).

If you have a complaint, you can contact:

a. The supervisor - Dr Martin Barwood 0113 283 7100 ext 285, m.barwood@leedstrinity.ac.uk

b. The Chair of the School Ethics Committee – Prof Mark Russell 0113 283 7100 ext 649 m.russell@leedstrinity.ac.uk

Who is funding the research?
This work is unfunded.

Who has reviewed the study?
This study has been scientifically and ethically reviewed by the School of Health and Social Science's Scientific and Ethics Review Committee and ethical approval has been granted.

Thank you
Thank you for taking the time to read this information sheet and for considering volunteering for this experiment. If you do volunteer for this experiment your consent will be sought on the following page. You will then be given a copy of this information sheet and your signed consent form, for you to keep.

CONSENT FORM

Principal Investigator: Mr Daniel Over
Telephone: 07584 902671
Email: 1400571@leedstrinity.ac.uk

Leeds Trinity University
Department of Sport, Health and Nutrition
Brownberrie Lane, Horsforth,
North Yorkshire, LS18 5HD

If Principal Investigator is a student:
Supervisor: Dr Martin Barwood
Telephone: 0113 283 7100 ext 285
Email: m.barwood@leedstrinity.ac.uk

STUDY ONE TITLE: The effect of surface body sprays on maximal and dynamic weightlifting performance

Please initial each box if content

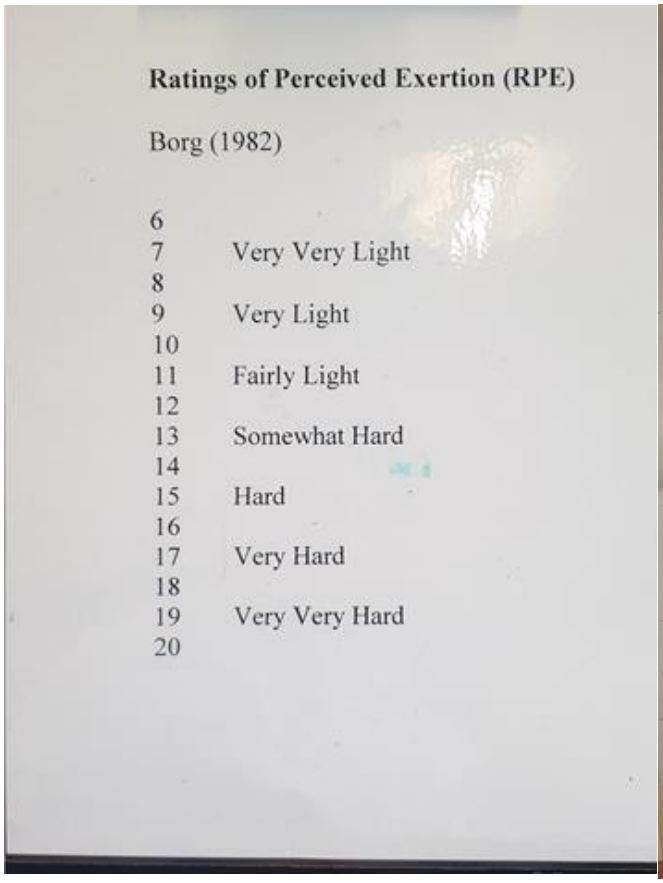
1. I confirm that I have read and understood the attached information sheet for the above study. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily.	
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.	
3. I understand that the results of this study may be published and / or presented at meetings. I give my permission for my anonymous data, which does not identify me, to be disseminated in this way.	
4. Data collected during this study *could* be requested by regulatory authorities. I give my permission to any such regulatory authority with legal authority to review the study to have access to my data, which may identify me.	
5. I agree to the data I contribute being retained for any future research that has been approved by a Research Ethics Committee for up to 6 years.	
6. I agree to take part in this study	
7. I consent for photographs of me to be taken during the experiment for use in scientific presentations and publications (with my identity obscured).	

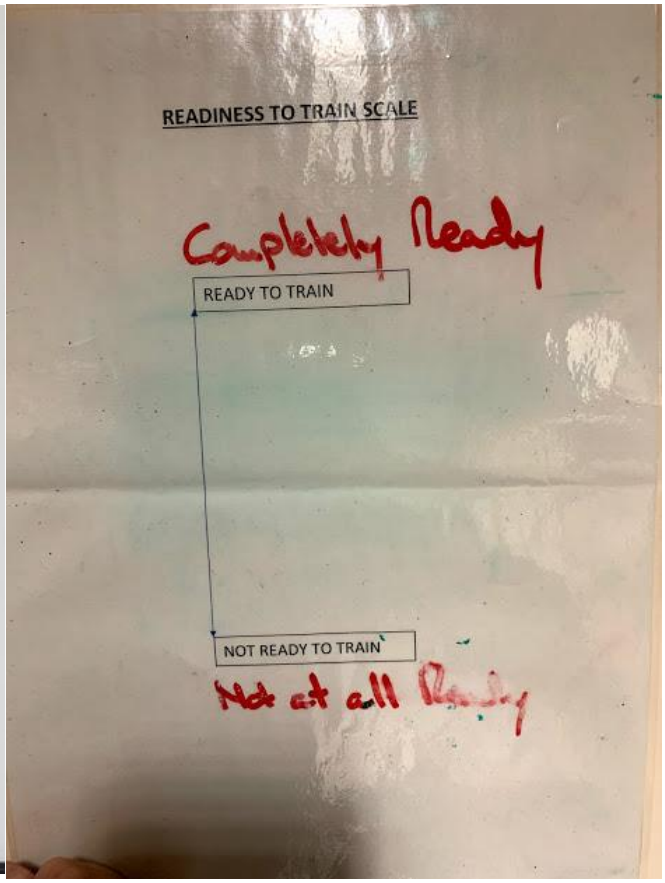
Name of Participant: **Date:** **Signature:**

Name of Person taking Consent: **Date:** **Signature:**

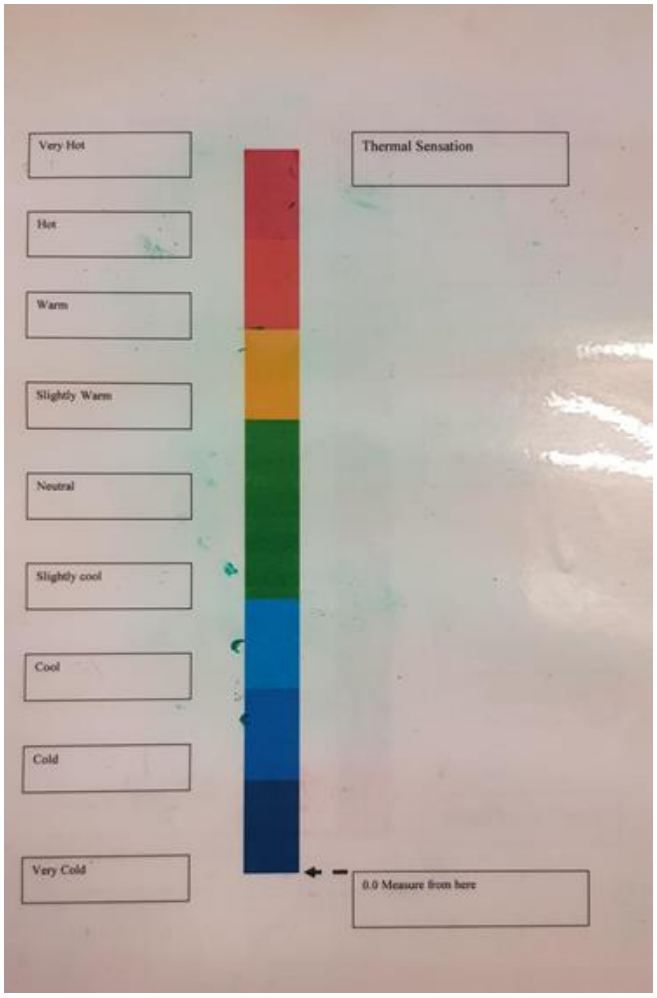
***Note**: When completed, one copy to be given to the participant, one copy to be retained in the study file*

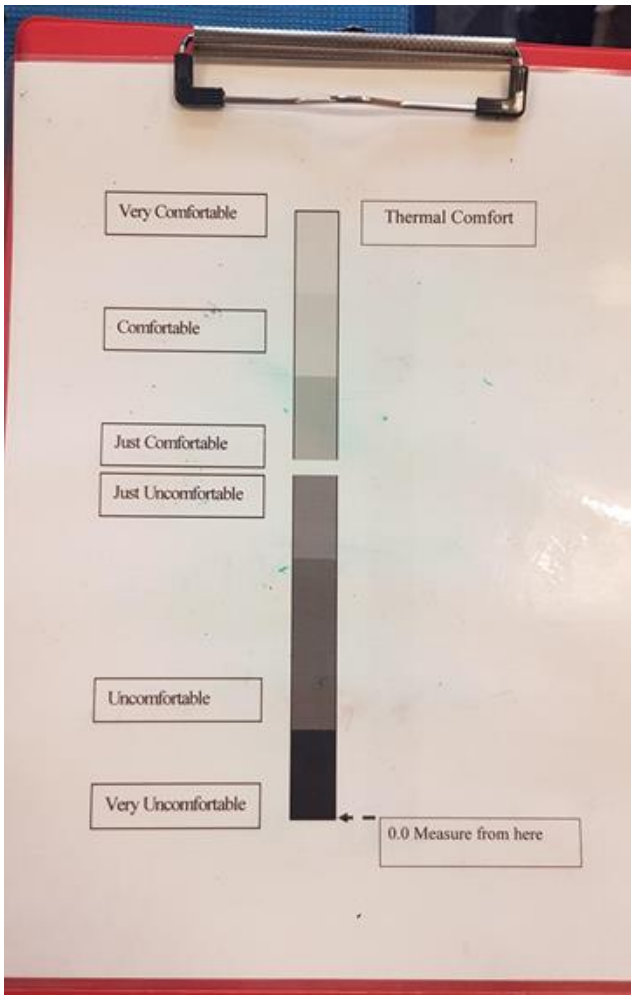
Appendix D – Rating of Perceived Exertion and Ready to Train scale used in experimental trials





Appendix E – Thermal sensation and Thermal comfort perceptual scales used in experimental trials





DEBRIEF FORM

Principal Investigator: Mr Daniel Over
Telephone: 07584 902671
Email: 1400571@leedstrinity.ac.uk

Department of Sport, Health and Nutrition

Brownberrie Lane, Horsforth,
North Yorkshire, LS18 5HD

If Principal Investigator is a student:
Supervisor: Dr Martin Barwood
Telephone: 0113 283 7100 ext 285
Email: m.barwood@leedstrinity.ac.uk

STUDY ONE TITLE: The effect of surface body sprays on maximal and dynamic weightlifting performance

DEBRIEF SUMMARY

Thank you for taking part in our study. We really appreciate and value the contribution you have made. This study sought to examine the effect of spray, applied to your legs, on maximal and dynamic weightlifting performance. The constituents of the sprays were deliberately concealed from you to avoid biasing your responses to the data we were collecting. We can now reveal that one of the sprays contained a low concentration of menthol and the second spray was a control (i.e. it did not contain menthol). We are interested in studying the effects of menthol on your performance as we have previously discovered that it enhances endurance exercise performance (i.e. aerobic cardiovascular activities), especially in hot conditions. We know that it helps people feel cool and more comfortable and lowers perceived exertion during exercise. In the present study, we were exploring whether it could also influence very high-intensity resistance exercise and muscular responses. The measurements we took were to help us answer this question. Please keep the focus of the study confidential so as not to bias any other participants' responses to the tests. Please feel free to ask any other questions you may have about the study and its design. Lastly, we would be grateful if you could recall your second and third visits to complete the study. Please could you guess which of the test conditions (i.e. visits) utilised the menthol and which one utilised the control (see below). Once again, thank you for taking part in our study. We really appreciate and value the contribution you have made.

Test of Treatment Blinding

Please circle your response

Visit 2 Menthol or Control or Not Sure

Visit 3 Menthol or Control or Not Sure