Effects of Whole Body Cryotherapy (-110°C) on Proprioception and indices of Muscle Damage.

Joseph T. Costello[1], Lynne A. Algar[1], Alan E. Donnelly[1]

[1]Department of Physical Education and Sport Sciences, University of Limerick, Castletroy, Limerick, Ireland

4.1 Abstract

The purpose of this study was to investigate the effects of Whole Body Cryotherapy (WBC) on proprioceptive function, muscle force recovery following eccentric muscle contractions and tympanic temperature (T_{TY}). Thirty-six subjects were randomly assigned to a group receiving two 3-minute treatments of -110 ± 3˚C or 15 ± 3˚C. Knee Joint Position Sense (JPS), maximal voluntary isometric contraction (MVIC) of the knee extensors, force proprioception and T_{TY} were recorded before, immediately after the exposure and again 15 minutes later. A convenience sample of 18 subjects also underwent an eccentric exercise protocol on their contralateral left leg 24 h before exposure. MVIC (left knee), peak power output (PPO) during a repeated sprint on a cycle ergometer and muscles soreness were measured pre-, 24, 48 and 72 h post-treatment. WBC reduced $T_{TY,}$ by 0.3°C, when compared with the control group ($p < 0.001$). However, JPS, MVIC or force proprioception was not affected. Similarly, WBC did not effect MVIC, PPO or muscle soreness following eccentric exercise**.** WBC, administered 24 h after eccentric exercise, is ineffective in alleviating muscle soreness or enhancing muscle force recovery. The results of this study also indicate no increased risk of proprioceptive-related injury following WBC.

Key Words: eccentric exercise, joint position sense, maximal voluntary contraction, muscle soreness.

4.2 Introduction

Cryotherapy, in the form of cold water immersion and ice packs, has been used for decades as a post-exercise recovery strategy in a variety of sports. The application of cold is believed to work by decreasing muscle temperature levels, diminishing pain and muscle spasm and reducing the inflammatory process; thus aiding the recovery process after trauma (Knight, 1995; Banfi et al., 2010). Cold water immersion has also been used before exercise (pre-cooling) or during exercise to improve endurance activities in humid conditions (Duffield et al., 2010). A new modality of cryotherapy, called Whole Body Cryotherapy (WBC), is currently being offered by clinicians as an alternative to cold water immersion or ice packs. WBC involves repeatedly exposing participants to very cold air (-110 °C) while dressed in minimal clothing for a short period of time (Westerlund et al., 2009). WBC is used in a clinical setting to treat the pain, edema and inflammation of various rheumatic diseases, so patients can do therapeutic exercises after WBC (Westerlund et al., 2003). In sports medicine, WBC is promoted as a treatment for muscle injuries, syndromes of overuse, and to enhance recovery between training sessions (Banfi et al., 2010). WBC has previously been shown to reduce skin (Westerlund et al., 2003) and oral (Taghawinejad et al., 1989) temperature, lower total oxidative status in plasma (Lubkowska et al., 2008), increase anaerobic capacity (Klimek et al., 2010), lower creatine kinase activity (Wozniak et al., 2007; Banffi et al., 2008) and alter the concentration of cortisol (Wozniak et al., 2007). As a result Klimek and colleagues (2010) suggest that this type of treatment should therefore be recommended during the recovery process due to the recognized benefits of cryostimulation/cryotherapy in athletes. However, despite the extreme temperatures utilised by this treatment, little is known about the potential of WBC to reduce proprioceptive function or enhance recovery from delayed onset of muscle soreness.

Proprioceptive acuity, which is a component of the sensorimotor system, has been defined previously as an individual's ability to sense joint position, movement and force to discriminate movements of their limbs (Riemann & Lephart, 2002). A decrease in proprioception acuity and/or diminished knee joint proprioception has previously been linked to rendering the knee less sensitive to potentially damaging forces and possibly at an increased risk for ligament injury (Baker et al., 2002). Despite a number of authors suggesting no detriment in joint position sense following cryotherapy (LaRiviere & Osternig,

1994; Thieme et al., 1996; Uchio et al., 2003; Dover & Powers, 2004; Wassinger et al., 2007), it is possible that the application of cold may decrease proprioception and predispose an individual to injury due to decreases in nerve conduction velocity, muscle force production, proprioceptive afferent information, or a combination of these factors (Hopper et al., 1997; Surenkok et al., 2008; Oliveira et al., 2010). The importance, for clinicians and sportspeople alike, of increasing the awareness of the potential effects of cryotherapy on proprioception acuity in healthy individuals has been highlighted previously (Oliveira et al., 2010). Several studies (Uchio et al., 2003; Dover & Powers, 2004; Wassinger et al., 2007; Surenkok et al., 2008; Oliveira et al., 2010) and a systematic review (Costello & Donnelly, 2010) have highlighted previously the limited research available on the effects of locally applied cryotherapy (the application of an ice pack to a joint or muscle group or the immersion of a joint(s) in cold water) on proprioceptive acuity. Further controlled and empirical studies are required to address this brevity of research, and also in the area of WBC.

Many sporting organisations, clinicians, coaches and athletes are currently using WBC, despite the limited number of publications in the area, and the current study aimed to address this deficit in the literature. To our knowledge, the effects of WBC on knee JPS, muscle force reproduction, recovery after muscle damaging exercise, or tympanic temperature (T_{TY}) have yet to be investigated. There were two distinct aspects to the current study, Experiment 1 focused on proprioceptive function and $T_{TY,}$ while Experiment 2 on recovery from eccentric muscle damage. Therefore, the purpose of this study was (1) to evaluate the immediate effects of WBC on proprioception and T_{TY} and (2) to evaluate the effectiveness of WBC in the treatment of muscle soreness and function following eccentric exercise damage.

4.3 Methods

Subjects

The study population, for Experiment 1, consisted of 36 healthy participants (age, mean ± standard deviation (SD), 20.8 ± 1.2 years, height 177.0 ± 4.8 cm, and body mass 76.0 ± 7.9 kg). Subjects were recruited from the University of Limerick's student population. The study was conducted in accordance with the Declaration of Helsinki and approved by The University of Limerick's Research Ethics Committee (ULREC: 09/47). After providing informed written consent, participants were randomly assigned, using a random number generator, to a cold group (WBC; 6 women and 12 men) or control group (6 women and 12 men). Participants completed a pre test questionnaire and were excluded if they had a history of lower limb injuries in the past twelve months, ear or vestibular conditions or if they had any contradiction to cryotherapy including Reynaud's disease. They were also excluded if they were not between the ages of 18 and 40, not physically active for an average of 3 days a week or not comfortable with being blind-folded during testing**.** Subjects were also instructed to refrain from consuming alcohol or caffeine 24 hours before testing commenced.

Experimental overview

The current study was a single-blinded randomized controlled trial with two independent variables. In Experiment 1 of the study (proprioceptive acuity following WBC), these variables including time (baseline, immediately post and 15 minutes post-intervention application) and treatment groups (3 minutes of WBC and a control). Concealed, random allocation was used to assign participant treatment group after baseline measurements. In Experiment 2 of this study (the effects of WBC on muscle force recovery following eccentric exercise) a convenience sample of 18 volunteers (9 in each group) were recruited from the original 36 participants. Similarly, there were two independent variables for this component of the study including time (baseline, 24, 48 and 72 hours post-treatment) and treatment group (3 minutes of WBC and a control). The main outcome measures of the Experiment 1, based on the right limb, were knee JPS, maximal voluntary isometric contraction (MVIC), muscle force reproduction of the right knee extensors and T_{TY}. The main outcome measures of Experiment 2, where 18 subjects underwent an eccentric muscle damaging protocol on their contralateral left limb 24hr before treatment, were MVIC (on the left knee extensors),

muscle soreness and peak power output (PPO) recorded during repeated sprints on a cycle ergometer.

Whole body cryotherapy protocol.

Participants were exposed, in pairs, to either a cold or a control treatment in a cryogenic chamber at the Shannon Cryotherapy Clinic in Ennis, County Clare, Ireland. For the cold group, WBC exposures were administered in a specially built, temperature-controlled unit (Zimmer Elektromedizin, Germany), which consists of two rooms (-60 °C and -110 °C). The temperature of the therapy-room remained at a constant level (-110 ± 3°C [mean ± SD]), and the air in the room was dry and clear. Subjects entered and stood in the first room (-60 ± 3°C) for 20 seconds before entering the second room (-110 °C ± 3°C) for three minutes. The duration and temperature of the cold chamber were similar to that utilised elsewhere (Westerlund et al., 2003; Westerlund et al., 2006; Westerlund et al., 2009; Klimek et al., 2010). Subjects were instructed by the trained machine operator to walk slowly around the chamber and to flex and extend their elbows and fingers throughout the 3 minutes. For the control group, subjects followed the very same procedures as the cold group except both chambers were set at a temperature of 15 ± 3°C. In the chamber, both groups wore two pairs of gloves and their noses and mouths were secured with a surgical mask; their ears were covered with a woollen headband and they had their own dry shoes and socks. All participants wore shorts, male participant wore nothing above the waist during the exposure and females wore crop tops or sports bras. Glasses, contact lenses and all jewellery and piercings were removed before entry to the chamber.

All subjects repeated the treatment (either -110 ± 3°C or 15 ± 3°C), after a lapse of 2 hours. After the first visit to the chamber, the subjects were randomly chosen to complete either knee JPS or MVIC and force-reproduction assessments. The remaining tests (either knee JPS or MVIC and force-reproduction) were completed after the second visit to the chamber. The order of the testing for each subject was randomised. Baseline tests (knee JPS or MVIC and force reproduction) were completed immediately before exposure to the chamber and post-tests followed immediately after each exposure (within 2-3 minutes) and again 15 minutes later. Approximately two hour after the first exposure, participants completed the remaining

pre-tests and again entered the chamber. This time lag of two hours between treatments has been recommended by the manufactures and used extensively by the operators of the chamber in Ennis.

Experiment 1

Knee Joint Position Sense.

Active ipsilateral limb repositioning of the right knee was assessed after passive positioning, using an electrogoniometer placed at the lateral aspect of knee joint (Panics et al., 2008). This measurement has been validated as reliable in the clinical setting and has been suggested as the most appropriate test for determination of JPS in clinical studies (Olsson et al., 2004). This device used was a Biometrics™ electrogoniometer with an ADU301 angle display unit. This device has been validated previously with accuracy of ± 0.5 degrees (Rowe et al., 2001). To reduce the contribution of vestibular and visual input, participants wore blind-folds and headphones, over which white noise was played during the testing procedures. Before commencing testing, all participants were familiarised with the procedures by explanation, demonstration and at least three practise repetitions a minimum of 24 hours pre-testing and again on the day of testing, immediately before the pre-testing. Subjects were positioned in a seated position where the leg was resting at approximately 90° of flexion and the popliteal fossa did not touch the edge of the seat (Panics et al., 2008). The limb was then extended by the examiner at a slow steady speed (~10°/s) to a randomly assigned index angle between 10° and 30°, 30° and 60° or 60° and 90° of flexion. The examiner asked the subjects to hold this position for ~ 5 seconds (Olsson et al., 2004), which the subject was asked to remember with particular emphasis on the knee joint, and then the examiner returned the leg to its starting position at the same angular velocity. This 5 second time period enables the subject to become aware of the position of their limb. Subjects were then asked to actively reproduce the predetermined target angle with the ipsilateral limb. Subjects attempted to actively replicate the predetermined angle three times and the average was recorded. After the assessment of each angle, subjects were asked to leave the chair and walk around briefly. This assisted the subjects to concentrate on the new test angle and not the previous angle.

Maximal Voluntary Isometric Contraction (MVIC).

MVIC of the right knee extensors was recorded in a seated position using a Tornvall Chair. The subject was seated in an upright position with their right knee flexed at 90 degrees. A strap placed around the ankle was connected to a pre-calibrated load cell (Novatech, Hastings, UK), attached by an inextensible bolt to the chair. An analogue signal from the load cell was digitised using a recording system (Powerlab 4/25T, ADInstruments, Oxfordshire, UK) and recorded on a PC running Chart^{TM} 5 software (ADInstruments, Oxfordshire, UK). Participants were seated with arms crossed against the chest, and the hips were tied down to isolate the knee extensors. Participants were counted down from 3 and then asked to maximally contract their right leg for 3 seconds. The subjects performed the test 3 times with a minimum of 1 minute rest between each repetition. The maximum value of the 3 trials was recorded as the result. The subjects were given constant verbal encouragement and received visual feedback from a monitor throughout all MVIC tests. All participants were familiarised with these procedures as described previously.

Force-reproduction.

Force-reproduction testing was performed with the subject seated and positioned in the same position as for MVIC testing immediately before entering the chamber, after the cryotherapy treatment (within 3 minutes) and again 15 minutes later. A modified procedure based on that used by Dover & Powers (2003) was used in the current study. A target force equivalent to 25% and 50% of the MVIC was used for all subjects. To begin the force reproduction measurement, the subject attempted to extend their knee with sufficient force, while receiving visual and verbal feedback, until the target force being produced (either 25% or 50% randomly assigned) was reached. A computer screen was positioned on the desk in front of the subjects so that they could easily see the screen and the forces they produced during the entire length of the trial (Rubley et al., 2003). Each volunteer's individual target force (25% or 50% of their MVIC) was displayed as a horizontal line (in black). A second line (in red) represented the instant output of the volunteer's isometric force. Volunteers were instructed to match the force output line with the target line. Visual feedback was then removed and the subjects were instructed to reproduce the force after 10 seconds. When the subject verbally indicated that he or she had achieved the target force, *T1* was recorded for 3 seconds. The measurement was repeated 2 more times for a total of 3 trials at both angles. The error score for each trial was calculated as the mean absolute difference between the target force and the

reproduced force (Dover & Powers, 2003). All participants were again familiarised with this procedure as described previously.

Tympanic Temperature.

A Braun ThermoScan ear thermometer, (model PRO 4000, Braun, Kronberg, Germany), was used to measure tympanic temperature. The ear was tugged and the probe placed snugly into the external auditory canal of the right ear (Dzarr et al., 2009). The probe remained in this position briefly (1–2 seconds) until the machine bleeped to signal a recording had been taken. Tympanic temperature was recorded before entry to the chamber and 3, 8, 15 and 20 minutes after exiting the chamber. The same experimenter recorded all tympanic temperatures.

Experiment 2

Subjects

In addition to participating in Experiment 1 a convenience group of 18 subjects (age, mean ± (SD), 21.2 ± 2.1 years, height 177.5 ± 5.1 cm and body mass 77.2 ± 9.6 kg), sourced from the original 36 subjects, voluntarily agreed to participate in the second component of the study. Nine subjects participated from both the cold (2 women and 7 men) and control groups (2 women and 7 men). For these 18 subjects who participated in Experiment 2, the exposure commenced 24 hours following eccentric exercise.

Eccentric exercise protocol.

Immediately after the pre-tests on day one, the volunteers completed an eccentric exercise bout consisting of 100 high-force maximal eccentric contractions of the left knee extensors. We used an eccentric muscle damaging protocol used previously in a similar study (Mackey et al., 2004). These contractions were performed on an isokinetic dynamometer (Con-Trex MJ; CMV AG, Dubendorf, Switzerland) set at an angular velocity of 1.57 rads.s^{-1}. The 100 contractions were divided into 20 sets of 5 repetitions, with a minimum rest period of 1 minute between sets. Participants were in a seated position with strapping isolating movement of the knee joint around the chest and opposite leg. The left leg in all subjects was

tested and was strapped securely to the lever arm of the isokinetic system. The volunteers were required to maximally resist the forced lengthening of their quadriceps through a range of motion, from almost full extension to almost full flexion (Mackey et al., 2004). The subjects were given a standardized visual and verbal encouragement throughout the duration of the protocol.

Maximal Voluntary Isometric Contraction (MVIC).

The 18 subjects participating in Experiment 2 completed the same MVIC protocol, as described earlier, except the contractions were performed on their contralateral left limb.

Peak power output (Maximal cycling repeated-sprint test).

The maximal cycling repeated-sprint test used in this study is similar to that used elsewhere (McGawley & Bishop, 2006). This test was conducted on day 1 (approximately 24 hours before the first visit to the chambers) and again 24, 48 and 72 hours following exposure. The reliability of this outcome measure in terms of work and power has been established previously by McGawley & Bishop (2006). All trials were performed at the same time of day, and subjects were instructed not to undertake strenuous exercises throughout the duration of the testing. Following a standardised five minutes warm-up at a self-directed pace, each subject performed a 5 x 6 second maximal cycle repeated-sprint test on a Monark cycle ergometer (874E, Vansbro, Sweden) that was dynamically calibrated. The 5 x 6 second cycle test comprised of five 6-second maximal sprints departing every 30 seconds. During the 24-seconds recovery period between sprints, subjects were permitted to turn the pedals at a self-selected pace. Subjects received a countdown before each sprint and performed the sprints in the standing position while receiving a standardised verbal encouragement. Like all the previous outcome measures, participants were familiarised with this procedure.

Muscle Soreness Questionnaire.

Muscle soreness was also assessed in the days following eccentric exercise with the aid of a questionnaire that has been used elsewhere in which a similar exercise protocol was used

(Mackey et al., 2004). Soreness was measured by self-palpation of the knee extensors at eight specified sites, corresponding to the proximal and distal regions of the knee extensor and flexors. Soreness was rated on a visual-analogue soreness scale, ranging from 1 (normal, no pain) to 10 (very, very sore), and total soreness was calculated as the sum of the eight values (Mackey et al., 2004).

Statistical Analysis.

The Statistical Package for the Social Sciences (SPSS) for windows (v16.0, SPSS Inc, Chicago, IL, US) was used for statistical analysis. For each JPS trial, the actual error was calculated by subtracting the reproduced angle from the target angle. A positive angle represents an overestimation and a negative value represents an underestimation. For the purpose of this study, the absolute mean error (the average error in the three trials ignoring the direction of the error), relative error (the average of the errors in the three trials taking into account the direction of the error) and variable error (the standard deviation of the three relative error measurements) were calculated (Olsson et al., 2004). In Experiment 1, the results were then analyzed using a mixed-design analysis of variance for repeated measure (ANOVA) to determine whether differences existed between control and cold application sessions (between subject), pre- and post-treatment (within subject) and the five sectors of movement (within subject). Pre-test PPO, MVIC (Experiments 1 and 2) and force reproduction data were normalised to 100% and analysed similar to JPS. The current study had an 80% power to detect a 1° difference in JPS error, a 7% difference in MVIC and a 0.2°C difference between cold and control conditions. Data are presented as means and standard deviation. For all analysis, statistical significant was set at $\alpha = 0.05$. All data are presented as mean ± SD.

4.4 Results

Experiment 1

Effects of WBC on Proprioception.

Comparisons of absolute, variable and relative angle errors for the two groups are displayed in Table 1. There was no significant between group differences for absolute ($F_{2,34} = 0.36$, P =

0.36, 1 - β = 0.22), relative ($F_{2,34}$ = 1.1, P = 0.34, 1 - β = 0.24), or variable ($F_{2,34}$ = 2.91, P = 0.062, 1 - β = 0.55), error over time. There was no significance differences in MVIC between groups following treatment ($F_{2,34}$ = 2.01, P = 0.89, 1 - β = 0.4). Similarly, participants' ability to reproduce either 25% or 50% of their MVIC was significantly better with visual and verbal feedback than without. However, there was no between group x time differences ($F_{2,34}$ = 0.05, P = 0.95, 1 - β = 0.06).

Tympanic Temperature (T_{TY}).

T_{TY} initial baseline values for the cold and control groups were 36.9 ± 0.3°C and 36.8 ± 0.3°C, respectively. The comparison of the change from baseline for both the cold and the control group revealed a significant difference in tympanic temperature, 3 and 8 minutes following exposure to the cold chamber (P < 0.001, Fig. 1). The lowest T_{TY}, 36.6 ± 0.4°C, was recorded in the cold group 8 minutes after leaving the chamber. Twenty-two minutes post treatment T_{TY} for the cold group returned to 36.8 ± 0.4°C. T_{TY} for the control group did not change significantly over time.

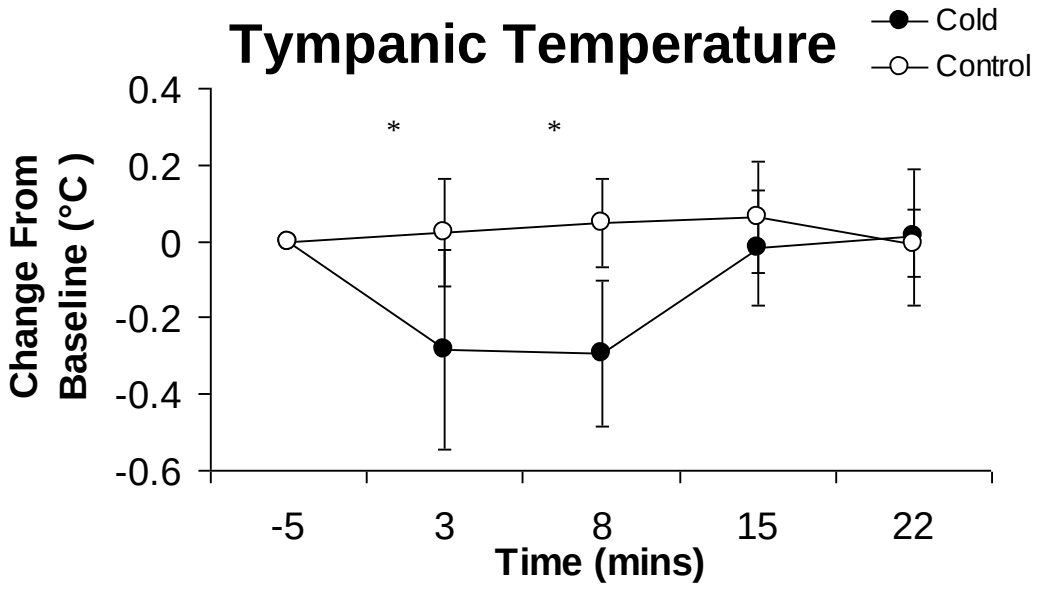

Fig. 1. Tympanic temperature calculated as change from baseline in degrees Celsius. Values are means ± SD for cold (n=18) and control (n=18). Cold group significantly different from control group (P<0.001, using a repeated measures analysis of variance and 95% confidence intervals) at 3 and 8 min after the climatic chamber.

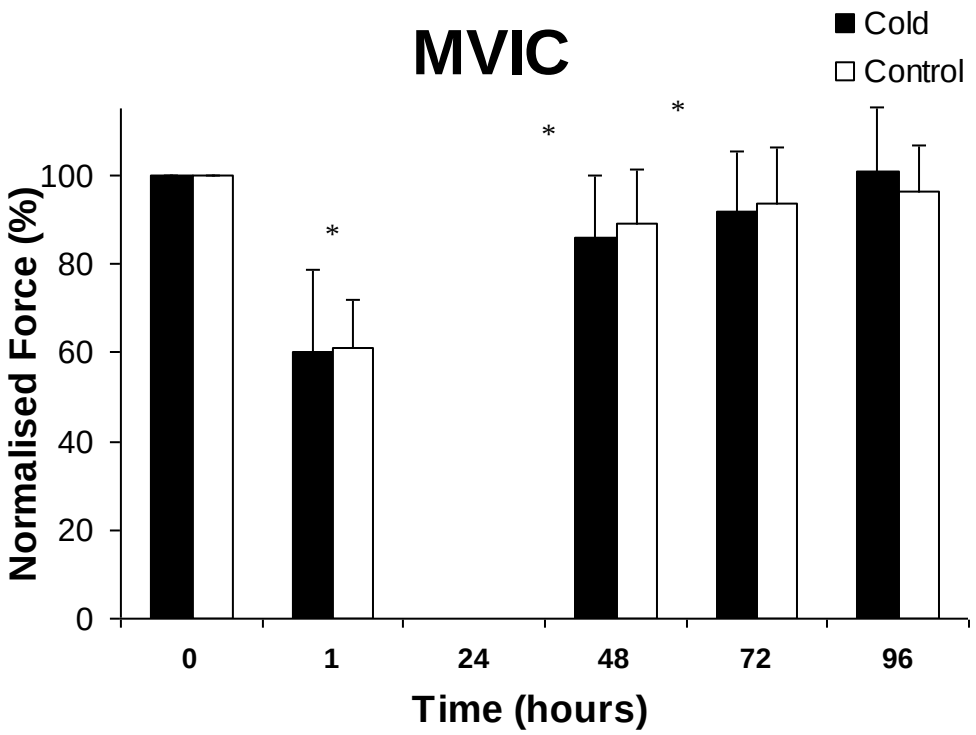

Fig. 2. Normalized maximal voluntary isometric contraction (MVIC) of the left knee extensors before and after eccentric muscle contractions (0 h) and in the days following treatment administered at 24 h. Values are mean ± SD for both the cold (n=9) and control (n=9) groups. *Both groups MVIC reduced significantly following eccentric exercise, P<0.05 using a repeated measures analysis of variance and 95% confidence intervals.

Experiment 2

Effects of WBC on muscle recovery following eccentric exercise.

MVIC significantly declined from 806 ± 138 Newtons to 483 ± 122 Newtons immediately after the damaging protocol ($F_{1,16}$ = 121.54, p < 0.001, 1 – β = 0.99, Fig. 2) and recovered thereafter to 98.7 ± 12.3% of pre-exercise values on day 5. The WBC treatment did not effect MVIC ($F_{3,48}$ = 0.88, p = 0.49, 1 – β = 0.23; Fig. 2) when compared to the control treatment in the days following treatment. Peak power output was also unaffected by the treatment ($F_{1,16}$ = 1.41, *P* = 0.24, 1 - β = 0.21). Similarly, there were no significant changes in visual analogue scale between groups over time ($F_{4,64}$ = 0.3, P = 0.88, 1 – β = 0.11; Fig. 3).

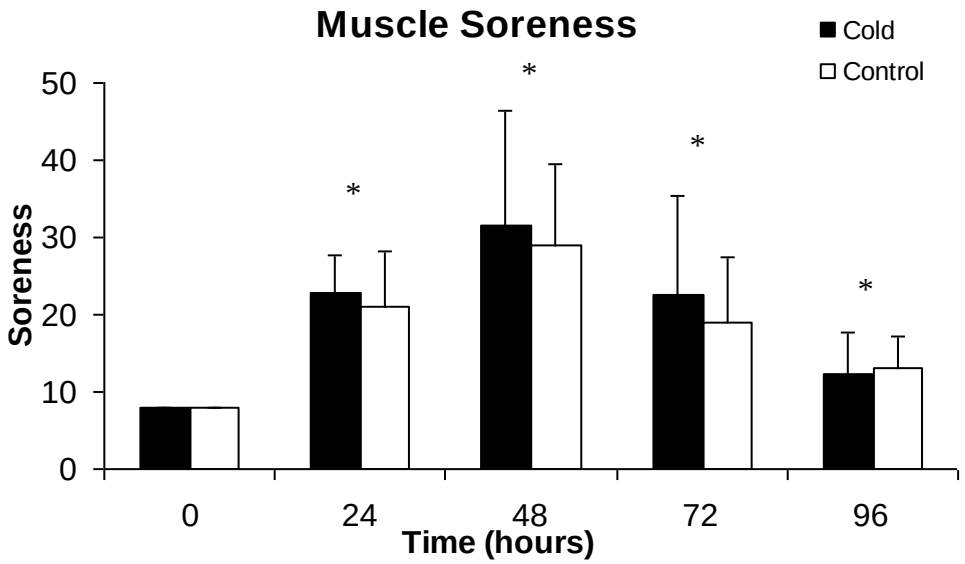

Fig. 3. Normalized rating of muscle soreness measured on a visual analogue scale, before (0 h) and after eccentric muscle damage and in the days following treatment administered at 24 h. Values are mean ± SD for both the cold (n=9) and control (n=9) groups. *Both groups muscle soreness increased when compared with baseline, $P<0.05$ using a repeated measures analysis of variance and 95% confidence intervals.

4.5 Discussion

The purpose of this study was to assess the immediate effects of WBC on knee joint position sense, maximal voluntary isometric contraction of the knee extensors, knee submaximal force sensation and tympanic temperature (Experiment 1). This study, in Experiment 2, also aimed to assess the effectiveness of WBC in treating indices of muscle soreness and function, in the days following an eccentric exercise bout. The results of the current study suggest that despite a significant reduction in T_{TY}, there are no detrimental effects (in terms of proprioceptive acuity) of using WBC before exercise. This may have future impact on the use of WBC before athletic participation or between training sessions. The results of this study also suggest cold air cryotherapy, administered 24 hours after an eccentric muscle damaging protocol, is ineffective in the treatment of muscle soreness or indices of muscle damage.

WBC and proprioceptive acuity

Despite the widespread use of cryotherapy before, during and after athletic participation there are conflicting results regarding the effect of cold therapy on joint stability, neuromuscular and proprioceptive acuity (Costello & Donnelly, 2010). Any impairment in proprioceptive acuity could result in an increased predisposition to knee injury. Our findings demonstrate that knee JPS remained unaltered following the recommended exposure to WBC. These results support that of other published material using other forms of cryotherapy (LaRiviere & Osternig, 1994; Thieme et al., 1996; Uchio et al., 2003; Dover & Powers, 2004). Despite the significant reduction in tympanic temperature reported in this study and the significant reduction in core and skin temperature reported in other studies (Taghawinejad et al., 1989; Westerlund et al., 2003) it appears that a healthy individual's ability to derive knee JPS is capable of withstanding the degree of cooling experienced in this cooling protocol. Since a methodology commonly employed by sports people was utilised in the current study, it does not exclude the possibility that a different protocol, using a different duration or temperature would reduce knee JPS.

This is also the first controlled study that has assessed force loss after WBC. Similar to the results ascertained from JPS, no significant between group differences were recorded for MVIC following the cold exposures. Previous studies have assessed MVIC in the hand follow cryotherapy applications with contradicting results (Coppin et al., 1978; Douris et al., 2003; Westerlund et al., 2009). Both Douris et al. (2003) and Coppin et al. (1978) have previously report a significant reduction in isometric grip strength follow cold water immersion (10°C). However, mirroring our results Westerlund et al. (2009) have found wrist flexion MVIC following both a single bout and repeated bouts of WBC was not significantly altered. It must be acknowledged that a potential explanation for the contrasting findings of the current study and those of Westerlund et al. (2009) to that of Douris et al. (2003) and Coppin et al. (1978) is the cryotherapy modality used. These results suggest the existence of a disparity in the degree of muscle and joint cooling that occurs during both the locally applied cryotherapy and standardised -110° Celsius WBC. Also individuals can remain in cold water for longer durations than in cold air chambers, up to thirty minutes at 14°C; it is possible that greater reduction in skin, joint and muscle temperature are experienced in the water. This

would be expected as a direct result of the greater thermal conductivity of water compared to air.

The relationship between a component of proprioception, force matching or force reproduction, in the knee joint and cryotherapy is poorly understood. Force reproduction in the present study involved the use of a reference force, 25 and 50% of a subjects' MVIC of the right knee extensors, and attempting to replicate that force. Research encompassing cryotherapy and force reproduction is severely limited, with only two studies to date having assessed the effects of cooling on submaximal force reproduction (Tremblay et al., 2001; Rubley et al., 2003). Both Rubley et al. (2003) and Tremblay et al. (2001) found separate cryotherapy applications to have no effect on force matching. Rubley and colleagues (Rubley et al., 2003) addressed the relationship between cryotherapy, in the form of a 15 minute ice bath immersion (10°C), from 1 inch (2.54 cm) proximal to the medial epicondyle to the distal end of the fingers, and sub-maximal isometric force variability in the finger and thumb. They concluded the application of ice had little effect on motor control of the digits, by stating that cryotherapy does not increase isometric targeting error or mean force standard deviation. Similarly, Tremblay et al. (2001) also found no influence on proprioceptive acuity in the quadriceps muscles after cooling in the form of a crushed ice application for a period of 20 minutes. Nonetheless, they concluded that care must be taken in return to participation as performance is believed to be effected after cryotherapy.

Peripheral signals of cutaneous and muscle origin are very likely to be reduced after cooling, but skin afferent reductions have less implication on proprioceptive acuity than muscle afferents (Tremblay et al., 2001). An explanation to why weight discrimination (force proprioception) may not be effected according to La Riviere and Osternig (1994) may be that inputs from joint receptors may be able to compensate for the reduction in muscle and skin afferents which were reduced during cooling.

Table 1. Comparison of absolute, relative and variable knee joint position angle errors of the right limb

	Pre-test (n = 18)		3 mins post (n = 18)		20 mins post (n = 18)	
	Cold	Control	Cold	Control	Cold	Control
Absolute error						
10-30˚	2.1 ± 2.2	2.1 ± 1.3	2.7 ± 1.7	2.3 ± 1.3	2.6 ± 2.2	2.4 ± 1.9
30-60˚	4.4 ± 3.0	3.0 ± 2.0	5.2 ± 2.4	2.9 ± 2.0	4.8 ± 2.5	2.8 ± 1.8
60-90˚	3.9 ± 2.0	2.4 ± 2.4	3.7 ± 2.5	1.5 ± 1.0	2.8 ± 1.7	1.7 ± 1.4
Relative error						
10-30˚	1.5 ± 2.6	-0.4 ± 2.4	2.0 ± 2.5	0.6 ± 2.6	1.1 ± 3.3	0.4 ± 3.0
30-60˚	4.0 ± 3.5	1.9 ± 3.1	5.2 ± 2.4	1.7 ± 3.0	3.7 ± 4.2	1.5 ± 3.0
60-90˚	3.4 ± 2.6	1.6 ± 3.0	3.5 ± 1.1	1.1 ± 1.4	2.2 ± 2.4	0.7 ± 2.1
Variable error						
10-30˚	1.0 ± 0.7	1.1 ± 0.7	1.0 ± 0.7	1.3 ± 0.8	1.2 ± 0.7	1.2 ± 0.6
30-60˚	1.9 ± 0.8	2.5 ± 0.9	1.7 ± 0.9	1.3 ± 0.9	4.2 ± 0.8	1.2 ± 0.8
60-90˚	1.6 ± 1.1	1.3 ± 0.8	1.4 ± 0.9	0.8 ± 0.5	1.7 ± 0.6	0.7 ± 0.8

Values are means ± SD for cold (n = 18) and control (n = 18). A negative value (-) represents an under estimation.

WBC and tympanic temperature

It has previously been reported that tympanic membrane thermometry is in good agreement with rectal thermometry (Dzarr et al., 2009). Scant data are available about thermal responses to WBC (Westerlund et al., 2003). Taghawinejad et al. (1989) found a slight decrease of

0.38°C in oral temperature, indicating that 90 seconds at -100°C does not affect core temperature. Unfortunately these authors did not report any values before or after the WBC. Westerlund et al. (2003) reported no significant decrease in rectal temperature following exposure to -110°C for 2 minutes. This is the first study that has investigated T_{TY} after a 3 minutes exposure to -110°C, preceded by 20 seconds standing in -60°C, with the results suggesting that it takes up to 15 minutes for it to return to baseline levels (Fig. 1). A potential explanation to why these results are in contrast to that of Westerlund et al. (2003) is the modality of core temperature recorded (T_{TY} and rectal) and the duration of the exposure (3 and 2 minutes). However, despite the use of similar thermometers in similar conditions, the reliability of the T_{TY} recording (Ganio et al., 2009) may not give an accurate recording of core temperature.

WBC and recovery from eccentric exercise

Despite the wealth of literature on cold water based rehabilitation techniques, published data on WBC is scarce (Banfi et al., 2009; Banfi et al., 2010; Klimek et al., 2010) and the scientific principal are often based on pilot studies (Banfi et al., 2010). Previous research in the area of WBC has successfully examined the effect of the treatment on other measures such as; skin temperature (Westerlund et al., 2003), neuromuscular adaptations (Westerlund et al., 2009), serum mediators of inflammation and serum muscle enzymes (Banfi et al., 2009) and haematological values in athletes (Banffi et al., 2008). However, there is limited evidence to support the use of WBC in the recovery of exercise induced muscle damage. To our knowledge this is the first controlled study that has assessed muscle force recovery following eccentric muscle damage.

The current study shows a reduction of approximately 40% in knee extensor MVIC immediately after eccentric exercise and returned to baseline approximately 96 hours after the exercise. However, there was no significant between group (cold or control) differences throughout the duration of the study. The MVIC results of the current study are supported by others using cold water immersion (Goodall & Howatson, 2008) and ice application (Howatson et al., 2005). However these results are in conflict to those of another study using a different cryotherapy protocol (Vaile et al., 2008). As this is the first controlled study which

has aimed to assess WBC as a rehabilitative therapy following eccentric exercise we cannot directly compare our finding to any other WBC study.

An individual's ability to repeatedly produce short, maximal efforts with brief recovery periods is an important fitness requirement of team-sport athletes. Improving the repeated sprint ability of athletes has become a focus of training and indeed rehabilitative programmes for many sports (McGawley & Bishop, 2006). The repeated cycling sprint test utilised in the current study is similar to that used elsewhere (McGawley & Bishop, 2006). The results of the current study suggest that two 3 minute bouts of WBC (-110°) is ineffective in altering PPO following this specific eccentric muscle damaging protocol, when compared to a cold group. However, the results of the current study did not show any decrease, in either the control or the cold group, following eccentric exercise. A potential explanation for this is that either the subjects had sufficiently recovered 48 hours after eccentric exercise, as PPO was not assess at 24 hours, or that eccentrically exercising one leg did not reduce PPO during the two-legged cycling protocol.

Soreness is the most commonly measured marker of eccentric muscle damage (Warren et al., 1999). The most commonly used method for determining soreness is by palpation with a self-report questionnaire or Visual Analogue Scale (Warren et al., 1999). However, the limitation with self-reported assessments is that the measures are subjective, and therefore a comparison between subjects in studies is not the most reliable method of assessment. The application of cold for relieving pain and acting as an analgesic is common practise in clinical, medical, and sports fields. This most likely reflects the potential of cold treatments to reduce the inflammatory response and consequent secondary muscle damage. As WBC has previously been shown to limit the increase of muscular enzymes creatine kinase (Wozniak et al., 2007; Banfi et al., 2009) and lactate dehydrogenase (Banfi et al., 2009), induce an increase of anti-inflammatory cytokines IL-10 (Banfi et al., 2009) and IL-6 (Lubkowska et al., 2010) and a decrease of pro-inflammatory cytokine IL-2, chemokine IL-8 and prostaglandin E_2 (Banfi et al., 2009) it is possible that this treatment may reduce muscle soreness after eccentric exercise. Different modalities of cryotherapy, including ice therapy (Howatson et al., 2005), cold water immersion (Goodall & Howatson, 2008), contrast water therapy (Vaile et al., 2008) and a combination of these treatments (Vaile et al., 2008), have been studied with

conflicting results reading muscle soreness recovery. The results of the current study suggest that two 3 minute bouts of WBC (-110°) is ineffective in alleviating subjective assessments of muscle soreness following this specific eccentric muscle damaging protocol. These findings are supported by others using different modalities of cryotherapy (Howatson et al., 2005; Goodall & Howatson, 2008).

Methodological considerations

The eccentric exercise bout used in this study may not accurately reflect the soreness and damage experienced during participation during other exercise. In addition, further controlled studies are required to assess the effect of WBC on muscle soreness, muscle function and peak power output administered at a different time point other than that used in the current study (24 hours post exercise) and in different populations, including an athletic population. The current study did not record skin, muscle or joint temperature and further research is required to prove whether WBC alters these temperatures. Also, using ear thermometers when the ears are cold may give unreliable results, and therefore the T_{TY} data needs to be treated with caution.

When compared to a control temperature the major findings of this investigation are, WBC significantly reduces T_{TY}; WBC does not deteriorate JPS, MVIC or force production and finally WBC, administered 24 hours following eccentric exercise, is ineffective in alleviating muscle soreness or improving recovery**.** To our knowledge this study is the first to report the effects of WBC on T_{TY}, knee JPS, MVIC and force reproduction. This is also the first controlled study to assess the effect of WBC, administered 24 hours after an eccentric muscle damaging protocol, on indices of muscle soreness and function (MVIC, PPO and subjective assessments of muscle soreness measured by questionnaires). Although we have reported no improvements following eccentric muscle damage these findings suggest that a healthy individual's ability to perform MVIC of the knee extensors or proprioceptive related tasks is unaltered, following WBC.

4.6 Perspectives

Performing eccentric contractions is a fundamental part of athletic performance and often leads to delayed onset of muscle soreness. This relatively novel modality of cryotherapy (WBC) has been advocated a means of recovery following athletic participation. Similarly, the use of WBC has been supported either before or between sporting activities for various reasons. The results of the current study suggest that although WBC does not increase the risk of proprioceptive related injury, it is ineffective in improving recovery if administered 24 hours after eccentric exercise. Data presented here can only be applied when WBC is administered 24 hours after exercise and does not exclude the potential positive effects of using a different treatment regimen or using WBC as a prophylactic treatment.

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