Effects of a Single Whole Body Cryotherapy (−110°C) Bout on Neuromuscular Performance of the Elbow Flexors during Isokinetic Exercise

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Key words
- peak torque
- power
- total work
- amplitude of electromyographic activity

Abstract

It has been demonstrated that body cooling may decrease neuromuscular performance. However, the effect of a single session of whole body cryotherapy (−110°C) on neuromuscular performance has not been well documented. Thus, the aim of this study was to evaluate the effects of a single exposure of WBC on elbow flexor neuromuscular performance. Thirteen physically active, healthy young men (age = 27.9 ± 4.2 years, mass = 79.4 ± 9.7 kg, height = 176.7 ± 5.2 cm) were randomly exposed to 2 different experimental conditions separated by a minimum of 72 h: 1) whole body cryotherapy – 3 min at −110°C; 2) control – 3 min at 21°C. All subjects were tested for maximal isokinetic elbow flexion at 60°.s⁻¹ 30 min before and 10 min after each condition. There were no significant differences in peak torque, average power, total work or muscle activity between conditions. Peak torque was lower at post-test compared to pre-test in both conditions (F=6.58, p=0.025). However, there were no differences between pre-test and post-test for any other variables. These results indicate that strength specialists, athletic trainers and physical therapists might utilize whole body cryotherapy before training or rehabilitation without compromising neuromuscular performance of the elbow flexors.

Introduction

Cryotherapy is a therapeutic technique which consists of application of cold in liquid, solid or gas form on regions of the body. A more recent form of cold therapy, called whole body cryotherapy (WBC), consists of brief exposure (2–3 min) to extremely cold air in a special temperature-controlled cryochamber or cryocabin, where the air is maintained at approximately −110 to −195°C [2, 13]. This cold therapy was used for the first time at the end of the 1970s by Toshiro Ymauchi in the treatment of rheumatoid arthritis [27]. Thereafter, it has seen extensive use in clinics to treat rheumatic diseases. Patients with this type of disease, when exposed to WBC, showed a decrease in pain [22], edema and inflammation, as well as musculoskeletal relaxation and an increase in range of motion [20]. Recently, WBC has gained wider acceptance in sports medicine venues as a method to enhance recovery from muscle damage, to prevent overuse syndrome, and to improve recovery between training sessions [2]. The WBC appears to have beneficial effects such as a decrease in the inflammatory response [3]. Moreover, it has been shown that WBC may decrease muscular enzymes related to muscle damage, such as creatine kinase [3,32] and lactate dehydrogenase [3]. However, the effects of WBC on recovery of muscle damage are still ambiguous [8, 13, 16]. It has also been reported that WBC treatment did not affect maximal voluntary isometric contraction of the knee extensors [8]. Westerlund et al. [30] observed that a single WBC session impaired drop-jump exercise performance. However, it did not affect neuromuscular performance of the wrist flexor muscles [30]. In contrast, Fricke et al. [14] observed that peak torque of the knee extensor and flexor muscles increased after a single session of WBC in healthy subjects. These conflicting results may be due to methodological differences, such as exercise protocol, type of muscle/joint measured, time elapsed between WBC and start of exercise, and time of exposure and number of sessions of WBC. Despite these controversies, WBC has also been used in clinical settings immediately before exercise to reduce pain, edema and inflammation [8, 31]. According to Westerlund et al. [31] and Costello et al. [8], these reductions would improve exercise session performance. Conversely, some
studies have reported a decrease in muscle performance due to body cooling by cold air exposure or cold water immersion [5, 7, 10, 21, 24]. However, the results from cold water immersion may not be applied to WBC [9]. In addition, the previous studies on WBC were on lower-body performance and their results may not be applied to upper-body performance [10]. Thus, the aim of the present study was to evaluate the effects of a single exposure of WBC on elbow flexor neuromuscular performance in healthy subjects. It was hypothesized that WBC exposure would impair neuromuscular performance.

Methods

Subjects

The sample size test for both WBC and control experimental conditions was determined in G*Power (version 3.1.2; Franz Faul, University of Kiel, Germany). The following design specifications were taken into account: \( \alpha = 0.05; (1-\beta) = 0.8; \) effect size \( f = 0.4; \) test family = F; test and statistical test = ANOVA repeated measures, within-between interaction. The sample size estimated according to these specifications was 12 subjects. 13 recreationally strength-trained young men (age = 27.9 ± 4.2 years, mass = 79.4 ± 9.7 kg, height = 176.7 ± 5.2 cm) volunteered to participate. Their training routine included 4–6 resistance training sessions per week, performing 6–16 sets per muscle group, and 6–15 maximum repetitions per set with 60–120 s of rest between sets. The minimum overall resistance training experience required to enter the study was one year. Subjects were informed of the purpose, procedures, possible discomforts, risks and benefits of the study prior to signing the written informed consent form. They were considered healthy and fit for physical exercise by answering no to all PAR-Q questions [28]. In addition, this study adopted the following exclusion criteria on the basis of Pobdielska et al. [26]: untreated arterial hypertension, cardiovascular and respiratory diseases, angina, peripheral artery occlusive disease, venous thrombosis, urinary tract diseases, severe anemia, allergy to cold, tumorous diseases, viral and bacterial infections, Raynaud’s syndrome, claustrophobia or convulsions. The present study was performed in accordance with the ethical standards of the IJSM [15] and approved by the Institutional Ethics Committee (Protocol: 71484/2012).

Experimental design

One week prior to beginning the study, subjects visited the laboratory for a familiarization session regarding the experimental procedures and for weight and height assessment. To test the effects of WBC on isokinetic elbow flexion neuromuscular performance, volunteers participated in 2 experimental conditions: 1) whole body cryotherapy (WBC) condition, exposure to WBC and 2) control (CON), without exposure to WBC. During the WBC condition, subjects were exposed to –110 °C for 3 min in a head out cryochamber (Fig. 1) based on gaseous nitrogen (Kryos Tecnologia, Brasilia, Brazil). The temperature and duration of WBC exposure were based on Costello et al. [8]. The volunteers wore bathing suits, gloves, socks and shoes with thermal protection to protect the extremities. In the CON condition, subjects remained in the cryochamber for 3 min at 21 °C. A random number table was used to randomize the order of each condition. All volunteers performed a standard isokinetic elbow flexion test 30 min before and 10 min after each condition. The isokinetic test consisted of 2 sets of 4 repetitions at 60 °.s\(^{-1}\) with 60 s rest between sets. To avoid circadian influence, subjects performed both conditions at the same time of day. Volunteers were instructed to avoid caffeine and alcohol intake for 24 h before testing and not to perform upper limb exercises for 72 h before testing.

Isokinetic assessment

Elbow flexion isokinetic peak torque, total work and average power were measured by the Biodex System 3 Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY, USA). Subjects were comfortably seated with their elbow on a Scott Bench (i.e. preacher curl). The lateral epicondyle of the humerus was used as a marker to align elbow rotation to the dynamometer’s lever arm. The forearm remained in a supinated position throughout the test. Gravity correction was obtained by measuring the torque exerted by the lever arm and the participant’s relaxed arm at full extension. Values for the isokinetic variables were automatically adjusted for gravity within the Biodex Advantage software. All procedures were in accordance with Flores et al. [12]. Calibration of the Biodex dynamometer was carried out according to the manufacturer’s specifications in the instruction manual. Participants received verbal encouragement throughout the testing session and all test procedures were performed by the same examiner for all participants.

Muscle activity

Surface electromyographic signals (EMG) were recorded from the biceps brachii by active bipolar electrodes (Ag/AgCl) with a 15 mm diameter and an interelectrode distance of 20 mm. The signals were digitally converted and amplified 100 times by Miotool (Miotec, Brazil – gain of 2000 V/V and common rejection mode of 110dB). Sampling frequency was 2000 Hz, and all SENIAM [17] recommendations for electrode position and asepsis for surface EMG for non-invasive assessment of muscles were followed. The skin was shaved and cleaned with alcohol. The
electrodes were placed on the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit. Data for mechanical variables were extracted from the isokinetic dynamometer and synchronized with EMG signals by the EMG equipment interface.

Digital signalling process
Digital signal processing was performed using computational routines written in Matlab 6.5 (Mathworks Inc., Natick, MA, USA). Initially, the torque signal was filtered by a fourth order, zero-lag Butterworth low-pass filter with cut off frequencies of 15 Hz [1]. For EMG data, the same filter was applied, but the band-pass cut-off frequencies were 20–500 Hz.

The peak torque burst for pre- and post-testing of WBC and CON conditions were chosen as a reference to identify changes in muscular recruitment due to WBC. The EMG analysis was performed in the signal corresponding to the concentric phase of the muscle action. The onset and end of the EMG burst were delimited through the angle signal [11]. A window of 2000 samples (1 s) corresponding to the middle part of the concentric action (Fig. 2) was used as a reference for the EMG parameters estimation.

The signals from the biceps brachii were normalized to the mean value of the pre-test EMG rectified burst of each measurement day/condition. After establishment of the burst boundaries and normalization, the amplitude of the EMG signal was calculated by root mean square (EMG-RMS).

Table 1
Means ± SD and [95% confidence intervals] of total work, power output and root mean square (EMG-RMS) during a standard test for isokinetic elbow flexion before and after whole body cryotherapy (WBC) and control (CON) conditions.

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>Difference a</th>
<th>ES</th>
<th>WBC</th>
<th>Difference a</th>
<th>ES</th>
<th>Difference between condition (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak torque (N.m)</td>
<td>66.3 ± 9.3</td>
<td>64.8 ± 10.1*</td>
<td>1.5 ± 2.9</td>
<td>65.5 ± 9.2</td>
<td>64.0 ± 9.4*</td>
<td>1.6 ± 4.1</td>
<td>0.17</td>
</tr>
<tr>
<td>Total work (J)</td>
<td>451.0 ± 61.3</td>
<td>445.1 ± 64.1</td>
<td>5.8 ± 20.6</td>
<td>456.0 ± 68.9</td>
<td>447.9 ± 70.2</td>
<td>8.1 ± 22.8</td>
<td>0.11</td>
</tr>
<tr>
<td>Average power (W)</td>
<td>49.5 ± 7.5</td>
<td>48.7 ± 7.3</td>
<td>0.8 ± 2.4</td>
<td>48.9 ± 8.2</td>
<td>48.2 ± 7.6</td>
<td>0.8 ± 2.5</td>
<td>0.10</td>
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<tr>
<td>RMS (%)</td>
<td>[45.4, 53.6]</td>
<td>[44.7, 52.7]</td>
<td>[−0.5, 2.1]</td>
<td>[44.4, 53.4]</td>
<td>[44.1, 52.3]</td>
<td>[−0.6, 2.1]</td>
<td>0.10</td>
</tr>
<tr>
<td>RMS burst (N)</td>
<td>125.2 ± 4.1</td>
<td>120.1 ± 24.6</td>
<td>5.0 ± 22.7</td>
<td>127.2 ± 3.3</td>
<td>126.8 ± 32.5</td>
<td>1.0 ± 30.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Difference a: pre-test – post-test. ES: Cohen’s d effect size. Difference between condition = main effect condition. *p < 0.05, lower than pre-test

Statistical analyses
Data are presented as mean ± standard deviation. The Shapiro-Wilk test was used to check data for normal distribution. Considering that data presented normal distribution, separate 2-way repeated measures ANOVAs [condition (WBC and CON) × exercise time (pre and post-test)] were used to analyse peak torque, total work, average power and EMG (RMS) across time. Intraclass correlation coefficient (ICC) was used to measure intra-rater reliability. The significance level was set at P < 0.05. Complementarily, the effect size (ES) calculation was used to examine the magnitude of each condition effect. Cohen’s ranges of 0.2, 0.5, and 0.8 were used to define small, medium and large d values obtained from differences between pre- and post-test scores divided by the pooled standard deviation [4].

Results
Baseline test/retest reliability ICC and coefficient of variation values for peak torque, total work, average power and for amplitude of the EMG (RMS) signal were 0.93 and 14%, 0.90 and 14.3%, 0.92 and 15.9%, 0.73 and 19.2%, respectively. For peak torque, there was no significant interaction (F = 0.0002, p = 0.99). There was no main effect for condition (F = 0.69, p = 0.42). The effect size for control and WBC condition were small (Table 1). However, there was a main effect for time with peak torque being lower in the post-test when compared to the pre-test (F = 6.58, p = 0.025; Table 1).

Fig. 2 Determination of the onset and the end of the concentric phase based on angle signal. The electromyographic signal corresponding to the central part of the concentric phase of the peak torque contraction (gray part of the signal burst) was used as reference for the comparisons between the experimental conditions.
Values for total work, average power and EMG (RMS) are presented in Table 1. There were no significant interactions for total work (F = 0.068, p = 0.80), average power (F = 0.0003, p = 0.98) or EMG (RMS) (F = 2.38, p = 0.18). There were no significant main effects for condition for total work (F = 0.35, p = 0.56), average power (F = 0.55, p = 0.47) and EMG (RMS) (F = 0.25, p = 0.65). Moreover, there were no significant main effect for time for total work (F = 2.7, p = 0.12), average power (F = 2.1, p = 0.17) or EMG (RMS) (F = 0.80, p = 0.39).

Discussion
The aim of this study was to evaluate the effects of a single WBC session (3 min at −110 °C) on neuromuscular performance in young men. Since other cold modalities using ice or cold water reported detrimental effects on performance [29], we hypothesized that WBC would result in a decrease in neuromuscular performance of the elbow flexors. However, we found no statistically significant differences between conditions. Although our hypothesis was rejected, these findings have a clinical relevance to those treating soft-tissue injuries and may also help decisions related to return to play after using this treatment modality.

Klimes et al. [19] examined the effect of a single session of WBC on maximal anaerobic power of the lower limbs. Subjects (15 men and 15 women) were exposed to 6 WBC treatments (3 min at −130 °C) once a day. After leaving the chamber in each session they performed a single Wingate test at 15, 30, 45, 60, 75 and 90 min post. There was no change in anaerobic power at any of the time points tested. However, they observed a shorter time to reach anaerobic power in men until 45 min and until 90 min in women compared to the initial time. According to the authors, repeated exposure to cold and the accompanying shivering thermogenesis cause an adaptable increase in the activity of anaerobic glycolytic enzymes. On the other hand, another study reported that flight time decreased during a drop-jump exercise after a single WBC exposure (2 min at −110 °C) [30].

The limitation of the present study is that it did not assess muscle fibre type composition [10]. Interestingly, studies on the effects of body cooling using different techniques have reported different findings on neuromuscular performance [5, 7, 21, 24]. They have shown a decrease in quadriiceps and hamstring peak torque after 40 min of exposure to 10 and 5 °C cold air [7]. The flight time, average force production and take-off velocity of a maximal rebound jump (stretch-shortening cycle) decreased in a dose-dependent manner after 60 min of 20, 15 and 10 °C cold air exposure [24]. Likewise, a reduction in peak torque, power and total work of the plantar flexors was observed after 20 min of cold water immersion (15 °C) [21]. Thus, it is important to highlight that the type of cold exposure may be one of the reasons for the difference between the present study and others reported here. Previous studies [5, 7, 21, 24] exposed subjects to cold water immersion or cold air, ranging in time from 20 to 60 min and in temperature from 5 to 27 °C. In the present study, our subjects were exposed to extremely cold air (−110 °C) for only 3 min. Hence, the discrepancies among temperature gradients, exposure time, and the conductivity of water and air must be considered when results from different modalities of cryotherapy are compared. Furthermore, in the present study, we investigated the effects of cold on upper-body muscle performance. Thus, the difference in results may be also related to the type of muscle action and muscle type/joint measured (upper body vs lower body) [10].

In the present study, there was no significant difference in muscle activity between the WBC and CON conditions. Thus, it seems that WBC exposure does not affect EMG signals of the elbow flexors. This is supported by Westerlund et al. [30] who did not observe any effect of a single WBC session on the EMG signals of the tibialis anterior or gastrocnemius medialis muscles during a drop-jump exercise, or on the carpi radialis during maximal isometric wrist flexion. In contrast, a negative effect of another type of cold exposure (water immersion) on EMG signals has been reported by other studies [6, 23, 25]. These studies revealed lower muscle activity of the forearm flexors during an isometric handgrip contraction at a muscle temperature of 20 °C compared to 27 and 35 °C [6]. A slight reduction in EMG amplitude during a maximal isometric handgrip test was observed after immersing the forearm in 20 °C water for 30 min compared to 30 °C water [25]. However, the EMG signal was markedly decreased after immersion in 10 °C water [25]. Mucke and Heuer [23] also reported a decline in EMG amplitude at 30% of maximal voluntary contraction of the elbow flexors after exposure to temperatures below 20 °C. Thus, the main reason for similar neuromuscular performances between WBC and CON conditions observed in the present study may be related to the thermoregulatory effects of WBC. A mild reduction in tympanic temperature from 36.9 °C to 36.6 °C after WBC has been reported [8]. This temperature returned to basal level 15 min after WBC exposure. Westerland et al. [31] measured rectal and skin temperature in healthy subjects before, during and after WBC exposure (2 min at −110 °C). Rectal temperature was unchanged during WBC exposure and maintained at 37.4 °C. However, after WBC, there was a slight continuous decrease in rectal temperature (37.16 °C).

The limitation of the present study is that it did not assess muscle temperature, skinfold thickness and other populations, such as women. It has been suggested that adipose tissue thickness may affect the cooling of underlying tissue [18]. Furthermore, it is known that muscle temperature can affect muscle performance [5, 10]. In accordance with Westerlund et al. [30], it is possible that WBC exposure caused a decrease in temperature of only the superficial muscles. Additionally, due to strong vasoconstriction and a short period of exposure (2–3 min), the critical muscle temperature that results in a decline of muscle strength (< 27 °C) [10] was probably not reached. This supposition is supported by Costello et al. [9]. They measured muscle temperature of the vastus lateralis before and 60 min after WBC (20 s at −60 ± 3 °C followed by 3 min and 40 s at −110 ± 3 °C). Baseline muscle temperature at a probe depth of 3 cm was 35.7 ± 0.7 °C. Compared to this, muscle temperature decreased 20 min after WBC exposure with the greatest reduction observed 60 min after treatment (1.6±0.6 °C). According to Costello et al. [9] it appears that muscle temperature starts to decrease 20 min after WBC. We could speculate that the 10 min rest interval between WBC exposure and the strength test may have been responsible for the results of the present study. However, our study aimed to apply a protocol used in clinical rehabilitation and training facilities. In these settings, patients and athletes usually begin resistance exercise 10 to 15 min following treatment.
In conclusion, the present study demonstrated that young men exposed to a single bout of WBC (3 min at −110 °C) did not decrease neuromuscular performance of the elbow flexors during isokineti exercise. Thus, WBC may be an alternative modality of cryotherapy for use in clinical and sports settings without impairing upper-body muscular performance. Additionally, with regard to practicality, WBC may be an effective alternative to cold water or cold air therapy due to lower exposure time. However, this consideration did not support the recommendation of using WBC before training and rehabilitation to improve recovery as well as to treat pain or injury. For the same reason, we assert that further studies on this topic are necessary to arrive at more precise conclusions and an improved understanding of the effects of WBC on the neuromuscular performance of different muscle groups. It is important to evaluate whether WBC is efficient in hastening recovery as well as treating pain or injury.

Conflict of interest: There are no conflict of interest declared among authors.

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