The Acute Influence of Whole-Body Cryotherapy on Electromyographic Signals and Jumping Tasks

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Abstract: Whole-body cryotherapy (WBC) is a popular treatment in prevention as well as post-injury therapy. The parameter used to assess the risk of injury is the ability of the human body to absorb and recover energy (elasticity). Therefore, this study aimed to assess the impact of whole-body cryotherapy (WBC) at 1 and 3 min intervals on the bioelectric activity of lower-limb muscles and countermovement jumps (CMJs) using trained subjects. A total of 24 individuals participated in the study. The mean age of the study group was 27.9 ± 7.9 years, mean body weight was 77.9 ± 8.8 kg, and mean body height was equal to 181 ± 6 cm. The training routine included 2–4 training sessions per week that lasted for at least 2 h at a time (mainly football). Along with the surface electromyography (sEMG) test of the rectus femoris, the BTS G-Sensor inertia measurement device was applied. After three minutes of WBC, a 6% difference in take-off force was noted, with a 7% \( p < 0.04 \) decrease in elasticity. In the bioelectrical activity of the rectus femoris after MVC normalization, differences \( p < 0.05 \) were noted 3 min after WBC. In this conducted study, a reduction in flexibility of the lower-limb muscle groups in the CMJ task was noted after 3 min of WBC.

Keywords: whole-body cryotherapy; vertical jump; bioelectrical activity

1. Introduction

Whole-body cryotherapy (WBC) is popular in prevention and post-injury therapy treatment. Extremely low temperatures (−110 °C to −135 °C) are used to stimulate the whole body, improving blood flow, contributing to improved healing and reduced excitability of the peripheral nerves, which results in reduced pain. Cryotherapy is widely used for motor system injuries to reduce swelling. WBC has a wide range of uses in sports, which means the studies on athletes are becoming increasingly precise. WBC influences changes in muscular response during physical tasks [1]. In the available research, WBC has positively impacted muscles during isokinetic testing and vertical jump tasks [2,3]. However, scientific reports indicate a reduction in nerve conduction velocity, joint position sense, and proprioception following cryotherapy.

The World Health Organization (WHO) recommends at least 60 min of moderate-to-vigorous physical activity (in the nature of everyday physical activity) to counter harmful cardiovascular, neuromuscular, and metabolic developments [4]. The decision to start performing a physical activity should be based on a gradual increase in load. Individuals with a low level of physical fitness who start performing a physical activity have lower muscle mass, and their neuromuscular system performs less well, which may contribute to their risk of injury, especially in team games [5,6]. According to Hedstrom et al., more than 50% of all injuries occur while practicing sports [7]. Quick changes toward a direction of movement, sudden stops and accelerations, or jumps require an adequate level of
lower-limb power. In team and individual disciplines, jumping is often used as a form of training [8,9]. The jumping task is associated with the properties of the neuromuscular system, which is responsible for muscle coordination during jumping. The ability of the human body to absorb and recover elastic energy is observed within the tendinomuscular groups. One of the most frequently used tests is the countermovement jump (CMJ). The CMJ is appealing because it is quick to perform and non-fatiguing, and it requires minimal familiarization, yet can yield valuable insight into an athlete’s neuromuscular and tendinomuscular groups [10,11].

The use of jumping is also applied in return to physical activity in case of injury. Plyometrics (jumping exercises such as CMJ) is used to rehabilitate the musculoskeletal system. In the available scientific data, there is evidence to suggest that plyometrics is an effective tool for increasing tendon stiffness, improving jumping, lower body strength, and muscle mass [12]. In the rehabilitation of the musculoskeletal system, WBC is often used as a form of pre-exercise for people who have suffered sports injuries. The muscle power generated during this jumping exercise can be very high, despite the low energy cost involved [13].

In one of the studies available in the literature, after WBC with varied exposure times, Vieira et al. recorded lower values in jump heights, muscle power, and a maximal velocity of vertical jumps [12]. Selke et al. recorded a reduction in gastrocnemius and vastus lateralis after exposure to low temperatures [13]. Furmanek et al. and Alexander et al. noted changes in the dynamic stabilization of lower-limb joints after cryotherapy and revealed that local cryotherapy might increase the risk of injury [14,15]. Some authors suggested that there was insufficient evidence to support the use of WBC after exercise to prevent and treat muscle soreness in adults [16,17]. As stated by Costello et al., there is a lack of evidence of the best prescription for WBC [18]. Few studies can be found that determine the influence of exposure of WBC to biomechanical parameters of lower limbs in bioelectric activity and CMJ [14]. The current state of research does not provide comprehensive or clear guidelines regarding the application of cold treatment and its direct effect. It has been hypothesized that there are differences between the topical exposure of cryotherapy and WBC and the musculoskeletal system. In the presented research, our study aimed to evaluate the parameters of vertical jumps after exposure to WBC in physically active individuals during competitive fixtures. Therefore, the present study evaluated the effect of WBC on selected biomechanical parameters (lower-limb bioelectric activity and CMJ) of physically active subjects exposed to extremely low temperatures.

2. Materials and Methods

2.1. Study Participants

The study included 24 subjects (mean ± SD age 27.9 ± 7.9 years, body mass 77.9 ± 8.8 kg, height 181 ± 6 cm). They were the target group of the research, and who volunteered to participate in the research. They served as their own controls. The inclusion criterion was a training routine of 2–4 training sessions per week that lasted for at least 2 h. Participants were familiarized with the experimental procedures and associated risks. Prior to the examination day, the participants did not exercise for 24 h. The following exclusion criteria were adopted: past injury, untreated arterial hypertension, cardiovascular or respiratory diseases, angina, peripheral artery occlusive disease, venous thrombosis, urinary tract diseases, severe anemia, cold allergies, tumor diseases, viral and bacterial infections, Raynaud’s syndrome, claustrophobia, or convulsions. Group’s characteristics are shown in Table 1.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>(Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>27.9 ± 7.9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>77.9 ± 8.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181 ± 6</td>
</tr>
<tr>
<td>Limb domination</td>
<td>23 right/1 left</td>
</tr>
<tr>
<td>Thigh circumference (cm)</td>
<td>54 ± 4.7</td>
</tr>
<tr>
<td>Shank circumference (cm)</td>
<td>38.9 ± 3.1</td>
</tr>
</tbody>
</table>

### 2.2. Ethical Considerations

This research was approved by the Bioethical Committee at the Medical University in Wroclaw (decision no. KB 165/2018). Before commencing the study, each participant was informed of its aim and of the procedure’s details. All individuals who took part in the study gave their informed consent to participate and were told that they could withdraw from the study without having to provide a reason for their decision.

### 2.3. Method

#### 2.3.1. Data Collection

This study was carried out as a prospective, single-center, controlled, non-interventional, open-label, and observational study. It adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies [19]. Before commencing actual measurement, necessary anthropometric data were collected (body mass, body height, absolute length of lower limbs). The vertical jump (CMJ) and surface electromyography (SEMG) tests were conducted before and after whole-body cryotherapy (WBC). The participants did not perform warm-up or stretching exercises for 30 min before the measurements. The individuals from the studied group were familiarized with the countermovement jump (CMJ) technique and the SEMG measurement method. Before WBC, CMJ was measured, followed by the SEMG test of the rectus femoris muscle, in study group subjects. The individuals from the studied group were prepared before WBC according to the methodology for conducting the procedure [20]. The examined individuals then were exposed to whole-body cryotherapy for 3 min. The participants were pre-cooled at $-60^\circ$ for 30 s, and subsequently, they were exposed to $-135^\circ$ for 3 min in a cryo-chamber; the cooling agent were vapors of liquid nitrogen. The next measurement of CMJ and SEMG of the rectus femoris was taken after 1 min and 3 min of WBC. The distance between the cryo-chamber and the room in which the measurements were taken was 15 m, and the temperature in it was between 21 °C and 25 °C.

#### 2.3.2. Data Analysis

Three vertical jump tests (each vertical jump test comprised three jumps) were performed: before WBC, after 1 min of WBC, and after 3 min of WBC. The examined individuals performed three CMJs at one-minute intervals. The CMJ jump test was conducted with hands on hips and to the maximum height possible. A BTS G-SENSOR inertia measurement instrument (BTS Bioengineering Corp., Quincy, MA, USA) was used to assess selected variables that characterize vertical jumps. The inertia sensor was attached to the S1 height using a dedicated strap. The device was equipped with a three-axis accelerometer with an option of sensitivity change ($+−2G$, $+−4G$), a three-axis gyroscope with an option of sensitivity change ($+−300 \, \text{o/s}$, $+−1200 \, \text{o/s}$), and a three-axis magnetic field sensor. Accelerometer records acceleration in three axes (vertical, anterior–posterior, and medial–lateral). The G-Sensor has been found valid for the assessment of physical activity in healthy adults with an inter-instrument correlation coefficient of between 0.90 and 0.99 and an intra-instrument coefficient variation of $≤2.5\%$ [13,20,21]. The baseline data were converted to numeric units in one axis or as a size of a complex vector (namely the sum of the sizes of all three
Complex vector data, used for recording selected variables that characterize the vertical jump, were used in the research. G-Studio version 3.0.18.0 software was used (BTS Bioengineering Corp., Quincy, MA, USA) to assess the parameters of the vertical jump.

CMJ is divided into weighing, unweighting, braking, propulsion, flight, landing, and corresponding parameters. The following were measured: maximum height—the maximum movement of the center of gravity (COG) (cm); maximum velocity—maximum velocity COG in the jump before flight/feet getting off the ground (m/s); take-off and landing force—the force needed to take off and to land (N); maximum concentric force—maximum force at the concentric phase (kW); elasticity—(K) is the ratio of the value of the cause of the strain (∆F) to a quantitative measure of strain (∆L) [22].

\[
K = \frac{\Delta F}{\Delta L}
\]

Surface electromyography (sEMG) is an experimental technique associated with obtaining, recording, and analyzing myographic signals. SEMG measurements were conducted using NeuroTrac® MyoPlus4 Pro (Verity Medical Ltd., Braishfield, UK), with 2 channels along with surface electrodes. The specification of the device fulfills the requirements as set out in ISEK and SENIAM publications. SEMG data were bandpass—filtered between 50 and 1000 Hz (finite impulse response (FIR) filter), rectified, and smoothed using a root-mean-square (RMS) value of 50 ms. The starting position for the measurement was seated on a chair with the knee and hip joints flexed at 90°. After identification of belly muscle and completing all necessary preparations of the body (the skin around the rectus femoris was shaved and cleaned with alcohol), measurement of bioelectrical activity of the rectus femoris at rest and during isometric activity was conducted: The extension of the knee joint was flexed at 90°, with the shank in a fixed position; electrodes were positioned on the fibula head and the distal part of the straight thigh muscle as recommended by the SENIAM protocol. SEMG activity results are shown in percentages due to performing the maximum voluntary contraction (MVC) trial of the rectus femoris muscle on the dominant limb of each examined participant. The results are presented in two units: in microvolts and as a percentage [23]. The bioelectric activity of the rectus femoris muscle was evaluated using disposable surface, self-adhesive silver–silver chloride electrodes (Ag/AgCl). The bioelectric measurement of the rectus femoris was assessed using Neuro Trac 5.0.117 software; a KR 2010 1/2018 (KrioSystem Life, Wroclaw, Poland) cryo-chamber was used.

2.3.3. Statistical Analysis

Statistical analysis was performed using STATISTICA software, version 12 (StatSoft, Inc., Tulsa, OK, USA). Arithmetic means and standard deviations were calculated for continuous variables. As indicated by the Shapiro–Wilk test, the distribution of the continuous variables did not comply with the normality assumption. Therefore, non-parametric tests were used. The Mann–Whitney U test was used to compare the pre- and post-WBC results. The Wilcoxon test was used for comparisons between the pre- and post-results. The level α < 0.05 was used for all comparisons. Statistical Power was carried out using G*Power software. The calculated statistical power was 0.80, and the significance level α < 0.05 of the sample size was 34.

3. Results

3.1. Countermovement Jump

The group differences for the CMJ components were not significant, except for the elasticity parameter. The results in the group before the cryo-chamber were different in the case of maximum jump height and maximum velocity from the results in people after the 3 min of WBC. The differences were not statistically significant (p < 0.33 for 1 min and p < 0.61 for 3 min). There were similar differences in the recorded maximum values for the take-off and landing force parameters in individuals exposed to WBC. Before exposure, the values were lower than after 3 min of WBC. Significant results were observed for the
3.2. Surface Electromyography

The results are presented in Tables 2 and 3. There was no difference in bioelectrical activity of the rectus femoris at rest 3 min after the individuals were exposed to WBC \((p < 0.46, p < 0.73)\). Significant differences were recorded using MVC normalization for the rectus femoris after 3 min. According to the data, the standard deviation in functional activity was very high. The average increased from 64 to 94, suggesting that the statistical significance went unrecorded due to high variability.

Table 2. The mean values and standard deviation of bioelectrical activity of the rectus femoris before whole-body cryotherapy and after 3 min of whole-body cryotherapy.

<table>
<thead>
<tr>
<th></th>
<th>Bioelectrical Resting Activity (µV)</th>
<th>MVC (%)</th>
<th>Bioelectrical Resting Activity (µV)</th>
<th>MVC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>1.75 ± 1.96</td>
<td>1.56 ± 1.26</td>
<td>64.12 ± 61.98</td>
<td>46.4 ± 10.1</td>
</tr>
<tr>
<td>After 1 min</td>
<td>2.82 ± 3.59</td>
<td>2.55 ± 2.68</td>
<td>61.53 ± 58.16</td>
<td>53.75 ± 7.24</td>
</tr>
<tr>
<td>Difference</td>
<td>61% (p &lt; 0.46)</td>
<td>63% (p &lt; 0.16)</td>
<td>4% (p &lt; 0.14)</td>
<td>16% (p &lt; 0.05) *</td>
</tr>
<tr>
<td>Before</td>
<td>1.75 ± 1.96</td>
<td>1.05 ± 1.26</td>
<td>64.12 ± 61.98</td>
<td>46.4 ± 10.1</td>
</tr>
<tr>
<td>After 3 min</td>
<td>2.21 ± 3.21</td>
<td>2.4 ± 3.3</td>
<td>94.26 ± 102.34</td>
<td>49.71 ± 8.84 *</td>
</tr>
<tr>
<td>Difference</td>
<td>26% (p &lt; 0.73)</td>
<td>45% (p &lt; 0.28)</td>
<td>26% (p &lt; 0.19)</td>
<td>7% (p &lt; 0.27)</td>
</tr>
</tbody>
</table>

* Statistically significant differences \(p < 0.05\).

Table 3. Mean values and standard deviation of selected component parameters of the countermovement jump before the exposure to whole-body cryotherapy and after 3 min of whole-body cryotherapy.

<table>
<thead>
<tr>
<th></th>
<th>Maximum Height (cm)</th>
<th>Take-Off Force (kN)</th>
<th>Landing Force (kN)</th>
<th>Maximum Concentric Force (kW)</th>
<th>Maximum Velocity (m/s)</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>46.39 ± 6.82</td>
<td>1.27 ± 0.47</td>
<td>2.18 ± 0.56</td>
<td>5.1 ± 1.54</td>
<td>3.12 ± 0.61</td>
<td>84.23 ± 18.21</td>
</tr>
<tr>
<td>After 1 min</td>
<td>49.9 ± 5.19</td>
<td>1.38 ± 0.5</td>
<td>2.22 ± 0.47</td>
<td>5.44 ± 0.5</td>
<td>3.33 ± 0.23</td>
<td>84.17 ± 7.31</td>
</tr>
<tr>
<td>Difference</td>
<td>8% (p &lt; 0.61)</td>
<td>9% (p &lt; 0.31)</td>
<td>2% (p &lt; 0.65)</td>
<td>7% (p &lt; 0.44)</td>
<td>6% (p &lt; 0.72)</td>
<td>1% (p &lt; 0.06)</td>
</tr>
<tr>
<td>Before</td>
<td>46.39 ± 6.82</td>
<td>1.27 ± 0.47</td>
<td>2.18 ± 0.56</td>
<td>5.1 ± 1.54</td>
<td>3.12 ± 0.61</td>
<td>84.23 ± 18.21</td>
</tr>
<tr>
<td>After 3 min</td>
<td>46.36 ± 5.19</td>
<td>1.34 ± 0.39</td>
<td>2.16 ± 0.49</td>
<td>5.75 ± 1.24</td>
<td>3.2 ± 0.3</td>
<td>77.96 ± 25.17</td>
</tr>
<tr>
<td>Difference</td>
<td>1% (p &lt; 0.27)</td>
<td>6% (p &lt; 0.46)</td>
<td>1% (p &lt; 0.27)</td>
<td>13% (p &lt; 0.14)</td>
<td>3% (p &lt; 0.71)</td>
<td>7% (p &lt; 0.04) *</td>
</tr>
</tbody>
</table>

* Statistically significant differences \(p < 0.05\).

4. Discussion

The World Health Organization (WHO) recommends at least 60 min of moderate-to-vigorous everyday physical activity to counter harmful cardiovascular, neuromuscular, and metabolic developments [4]. In following the WHO guidelines, a larger number of people take up physical activity. Different initial levels of preparation for performing physical activity lead to the increased risk of several types of injury. One of the parameters may include the elasticity of tissue. In a mechanical sense, elasticity refers to a response to the removal of applied force. Butler et al. explained that the concept of elasticity applies to deformable bodies, which store and give elastic energy [24]. Changes in elasticity may aim to increase or decrease its value. A reduction in elasticity may lead to an increase in the risk of injury to the soft tissues of the musculoskeletal system. On the other hand, a higher rate of lower-limb stiffness is associated with higher performance in athletic tasks such as jumping, skipping, throwing, endurance running, sprinting, and change-of-direction running [24,25]. In our study, changes in elasticity were aimed to reduce its value. The
reduction in elasticity was statistically significant after 3 min WBC, compared with the values recorded before WBC. Apart from the changes in elasticity, the eccentric force parameter, associated with storing energy when landing, also increased. According to Butler et al., both changes weigh in favor of increasing the risk of injury to bone structure. The changes in elasticity after WBC correspond to the observations made by Fullam et al. and Alexander et al. [14,15]. They analyzed the stability of ankle and knee joints after local cryotherapy. Decreased postural stability is a primary risk factor; a cold pack for 20–15 min negatively influenced dynamic postural-stability performance for lower-limb musculoskeletal injuries. The corresponding effect on tissues of WBC at \( -135 \degree C \) and at a much higher cooling agent temperature with a longer application period (local cryotherapy) may be associated with the spontaneous contraction of superficial vessels. This is in favor of the results obtained by Furmanek et al., who revealed that the use of cold compresses (with a higher cooling agent temperature) does not have an impact on knee joint position sense and force production sense [26]. A short-lasting, low thermal stimulus cannot affect mechanical response. Our study shows the significant effect of WBC exposure on CMJ in tissue elasticity, where the results changed in both groups before and after the 3 min exposition of WBC. In a study conducted by Struzik and Zawadzki, the authors state that, in a single vertical jump, leg stiffness appears relatively constant when measuring the parameters without exposure to a low temperature [22,27]. In our study, parameters differed after exposition on WBC, and less stiffness was observed before stimulation than after 3 min.

In youth sports, neuromuscular injury prevention programs (IPPs) can reduce the rate of injury by about 40%. Multimodal IPP includes balance, strength, power, and jumping exercises. Our study shows that the direct use of WBC may have a negative effect on strength and power. Faude et al. argue that neuromuscular performance can be regarded as the ability of the neuromuscular system to functionally control and drive movements by an appropriate use and coordination of muscular strength and endurance, muscle recruitment pattern, proprioceptive feedback, and reflex activity [28–30]. Another phase of searching for changes to the musculoskeletal system includes the SEMG test of the rectus femoris muscle. The SEMG amplitude did not increase significantly. In our study, resting bioelectric activity of the thigh muscle did not differ after the WBC exposition in 1 and 3 min (\( p < 0.46, p < 0.73 \)). By contrast, using MVC normalization, significant differences were noted after both 1 and 3 min.

This study has some limitations. Firstly, it was only conducted in one center, and the changes revealed in our study had a high standard deviation. Therefore, no significant effect after WBC may lead to the conclusion that WBC did not have an impact on the recruitment of motor units in our testing group. Secondly, the parameters analyzed in the study refer to young people with no comorbid conditions; therefore, the results should be treated with great caution. Given that WBC is very popular, future research should remain focused on the causes of the reduced elasticity in musculoskeletal system tissue.

5. Conclusions

In the rehabilitation of people with reduced muscle mass due to injury, plyometric exercises after WBC should be selected carefully. There are possible effects of using 3 min WBC driven by reduced elasticity. Depending on the assumed training goals, exposure times are recommended in order to develop power, speed, and capability. The WBC treatment can likely affect elasticity; therefore, its inclusion should be based on common sense and supervised by a physiotherapist, physician, or a coach responsible for motor skills.

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Institutional Review Board Statement: This research was approved by the Bioethical Committee at the Medical University in Wroclaw (decision no. KB 165/2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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