Whole-Body Cryotherapy’s Enhancement of Acute Recovery of Running Performance in Well-Trained Athletes

Malte Krüger, Markus de Mareés, Karl-Heinrich Dittmar, Billy Sperlich, and Joachim Mester

Purpose: To examine the effects of a whole-body cryotherapy (WBC) protocol (3 min at −110°C) on acute recovery and key variables of endurance performance during high-intensity intermittent exercise in a thermoneutral environment. Methods: Eleven endurance athletes were tested twice in a randomized crossover design in which 5 × 5 min of high-intensity running (HIR) were followed by 1 h of passive rest at −22°C, including either 3 min of whole-body exposure to −110°C (WBC) or a placebo intervention of 3 min walking (PBO). A ramp-test protocol was performed before HIR (R1) and after the 1-h recovery period (R2). Time to exhaustion (tlim) was measured along with alterations in oxygen content of the vastus lateralis (TSI), oxygen consumption (VO2), capillary blood lactate, heart rate (HR), and rating of perceived exertion (RPE) during submaximal and maximal running. Results: The difference in tlim between R1 and R2 was lower in WBC than in PBO (P < .05, effect size d = 1.13). During R2, TSI was higher in WBC during submaximal and maximal running (P < .01, d = 0.68–1.01). In addition, VO2, HR, and RPE were lower at submaximal level of R2 after WBC than in PBO (P = .04 to <.01, d = 0.23–0.83). Conclusion: WBC improves acute recovery during high-intensity intermittent exercise in thermoneutral conditions. The improvements might be induced by enhanced oxygenation of the working muscles, as well as a reduction in cardiovascular strain and increased work economy at submaximal intensities.

Keywords: intermittent exercise, ramp test, cooling, near-infrared spectroscopy, tlim

Many individual and team sports are characterized by 1 or more training sessions per day, with several competitions per week. Thus, any means to enhance recovery from and between strenuous high-intensity exercise may play an important role for success.1 Cryotherapy—the cooling of the body for therapeutic purposes—is 1 method applied to endurance-related sports events to enhance recovery from strenuous exercise and avoid or postpone exercise-induced hyperthermia.2 Different cooling methods like cooling garments, ice massages, cold drinks, or cold-water immersion (CWI) in the range of 10°C to 20°C have been applied successfully to enhance recovery-related variables such as time to exhaustion (tlim) or exercise-induced muscle damage.3–5 A new method in sports, called whole-body cryotherapy (WBC), is the exposure of the body to extremely cold air of −110°C to −130°C in temperature-controlled units.2 WBC may relieve soreness and reduce the initial muscle damage, as well as the secondary inflammation associated with exercise-induced muscle damage, by reducing muscle metabolism, receptor sensitivity, and nerve conduction velocity.6 WBC may decrease the acute inflammatory process by reducing, for example, serum soluble intercellular adhesion molecule 1.7 Consequently, fewer leukocytes are mobilized to the damaged tissue, resulting in decreased proinflammatory and increased anti-inflammatory response.7 However, there are only few studies analyzing the effects of WBC on recovery, so the evidence of its effectiveness is rather weak.8 Recently it was shown that partial-body cryotherapy (3 min at −110°C excluding the head) enhances the acute recovery of eccentric strength in high-intensity intermittent exercise.9 To the best of our knowledge WBC has not been applied in connection with acute recovery and intermittent endurance exercise so far. However, CWI, which induces thermoregulatory effects similar to those of WBC,10 showed improvements in 2-mile running performance11 and 4-km12 time-trial cycling, as well as 35-minute all-out cycling performance.13 Furthermore, improvements in submaximal performance were indicated by covering a greater distance during submaximal running.14 In addition to the mentioned reduction of muscle damage1 and the decrease in postexercise inflammation,15 further physiological responses induced by cryotherapy affecting acute recovery of endurance performance have recently been discussed: (1) Peripheral vasoconstriction leads to improvements in blood and oxygen supply in the working musculature during the subsequent exercise bout;16,17 (2) Cryotherapy induces lower submaximal heart rate and higher stroke volumes due to lower thermal stress,18 as well as the stimulation of the autonomic nervous parasympathetic activity, favoring acute recovery after exercise;19 (3) WBC increases norepinephrine,2 inducing a potential analgesic effect.8 Therefore, the aim of the current study was to determine the acute effects of a WBC protocol (−110°C) on recovery and key variables of endurance performance (tlim, peak oxygen uptake [VO2peak], work economy, alterations in oxygen content of the vastus lateralis) during intermittent high-intensity exercise in thermoneutral conditions.

Methods

Participants

11 healthy, nonsmoking, endurance-trained male athletes participated in the study (mean ± SD age 25.9 ± 2.1 years, body height 183.4 cm).
± 3.4 cm, body mass 76.3 ± 6.6 kg, body-mass index 22.7 ± 1.7 kg/m², body fat 10.7% ± 1.9%, lean body mass 68.1 ± 5.9 kg, VO₂peak 59.3 ± 5.3 mL·kg⁻¹·min⁻¹). The sample size was similar to those of studies investigating cooling and performance recovery in trained athletes, showing an average sample size of n = 10.2 ± 1.5. All participants were familiar with high-intensity running (HIR) and had been performing endurance training at least 3 times per week for at least 8 years. They were instructed to refrain from alcohol and caffeine 24 hours before the tests, to maintain their normal diet during the testing period, and to replicate their food intake on the day before and the morning of the 2 main testing days. No intensive exercise was allowed on the 2 days before testing. Furthermore, athletes were not allowed to use additional recovery methods like massages or consume any forms of nonsteroidal anti-inflammatory drugs. After being informed about and familiarized with the testing procedures, all volunteers gave their written consent to participate. The protocol and all procedures were conducted in accordance with the Declaration of Helsinki and approved by the ethical committee of the German Sports University Cologne.

Experimental Design

The athletes visited the laboratory 4 times. The first visit was for medical checkup and familiarization with WBC. Participants were excluded if they had any contraindications against WBC, such as claustrophobia, cold hypersensitivity, or abrasion injuries. During the second visit athletes carried out an incremental step test (starting velocity 2.4 m/s, increase 0.4 m/s every 5 min, treadmill gradient 1%) on a treadmill (Woodway ELG 90/200 Sport, Lorrach, Germany) for determination of VO₂peak and the running velocities during HIR. During the third and fourth visits the main tests were conducted in a randomized controlled crossover design. The design of these tests is presented in Figure 1.

The 2 test days were separated by at least 1 week. All athletes were tested at the same time of day and were randomly assigned to start with either the WBC or placebo intervention (PBO) using research randomizer (version 4.0, retrieved from http://www.randomizer.org/). The participants arrived at the laboratory at least 1 hour before the test for acclimatization. At first a ramp-test protocol to individual exhaustion was performed (R1). The protocol consisted of 3 submaximal 3-minute steps at 3.2, 3.6, and 4.0 m/s with a treadmill gradient of 1% and 30 seconds of rest for sampling of blood after each step. Thereafter velocity was increased to 4.4 m/s and remained constant while the treadmill gradient was increased by 0.5% every 30 seconds until exhaustion. After 5 minutes of recovery HIR was carried out, consisting of 5 × 5 minutes at 90% of maximum velocity reached during the incremental testing (second visit), with 4 minutes of active recovery between the intervals (60% of maximum velocity). HIR was followed by 1 hour of passive recovery, which was identically structured in both conditions except the implementation of one 3-minute session of WBC. During the recovery period the athletes remained seated in the conditioned laboratory (ambient laboratory temperature WBC 21.7°C ± 0.8°C vs PBO 21.7°C ± 1.0°C, humidity WBC 36.4% ± 7.7% vs PBO 35.8% ± 8.3%) and consumed 0.5 L of a standardized fluid (energy: 400 kcal consisting of 46.5 g carbohydrates, 15 g protein, 17 g fat) to avoid dehydration and to replenish depleted glycogen stores. The drink was warmed precisely to each athlete’s current core temperature (WBC 38.1°C ± 0.2°C vs PBO 37.9°C ± 0.3°C) to avoid additional cooling. After 45 minutes of rest WBC was administered by a temperature-controlled cryochamber (Zimmer MedizinSysteme GmbH, Ulm, Germany). The chamber system consisted of 3 separate rooms with constant temperatures of −10°C, −60°C, and −110°C. Before entering the unit all athletes dried themselves of any sweat. During WBC, mouth and nose were covered with a surgical mask, and cotton shorts, gloves, ear band, and dry socks and shoes were worn to protect the areas from frostbite. The participants traversed the first 2 chambers with −10°C and −60°C quickly and remained slowly walking for 3 minutes within the room at −110°C and 0% humidity. During PBO athletes walked slowly in the laboratory for 3 minutes (at 21.7°C ± 0.8°C and 35.8% ± 8.3% humidity). After a total of 60 minutes of recovery athletes performed a second ramp test (R2) with the same design as R1. We defined 𝑡Islm as the time from the beginning of the ramp tests to the participant’s individual exhaustion, indicated by jumping off the treadmill. Displays and time units were not visible to participants during the test to avoid external feedback.

![Figure 1 — Design of the main testing: ramp test 1 + 2 (R1, R2); whole-body cryotherapy (WBC); placebo intervention (PBO); 1st—5th measurements (R1pre, R1post, rest30min, R2pre, R2post) of body, skin, and core temperature (Tbody, Tskin, Tcore), and perceptual responses (PEPS, EZ Scale). | Measurement of tissue-saturation index of vastus lateralis (TSI), oxygen consumption (VO₂), capillary blood lactate (Lac), heart rate (HR), and rating of perceived exertion (RPE) during submaximal and maximal level of R1 and R2.](image-url)
Data Measurement

Core temperature \(T_{\text{core}}\) was measured via ingestible temperature-sensor capsules (MiniMitter Co, Inc, Bend, OR, USA). The participants ingested the sensor 4 to 5 hours before the beginning of R1 to ensure that it passed into the gastrointestinal tract as described earlier.\(^{14}\) \(T_{\text{core}}\) was recorded continuously every 60 seconds by a telemetric data receiver (MiniMitter). Skin temperature was assessed using a thermoimaging camera (Testo 880. Testo GmbH, Wien, Austria). Photos were taken of the head, trunk, arms, thigh, and legs at 5 separate time points (see Figure 1). Images were analyzed using the appending software (IRsoft Version 3.1 SP3, Testo GmbH, Wien, Austria). Mean skin temperature \(T_{\text{skin}}\) and mean body temperature \(T_{\text{body}}\) were calculated with a modification of the previously published equation by Hardy and DuBois\(^ {21}\): 

\[
T_{\text{body}} = 0.65 \times T_{\text{core}} + 0.35 \times T_{\text{skin}}.
\]

Furthermore, athletes answered a questionnaire consisting of 2 parts, with the first one addressing their perceived physical state (PEPS). The athletes were asked to judge spontaneously to what extent 20 given adjectives coincided with their current physical feeling on a 0-to-5 scale.\(^ {23}\) The second part of the questionnaire consisted of a short form to rate individual psychophysical state (EZ Scale; 16 adjectives on a 0-to-5 scale). As opposed to other psychological adjective scales (eg, the POMS), the EZ Scale analyzes not only emotional or psychological strain but also motivational state.\(^ {24}\)

During R1 and R2, respiratory data were recorded continuously with an open breath-by-breath analyzer (MetaLyzer 3b, Cortex, Leipzig, Germany), calibrated in the range of the anticipated fractional gas concentrations before each test with a precision 3-L syringe (Cortex, Leipzig, Germany) and calibration gas (15.8% \(O_2\), 5% \(CO_2\) in \(N_2\), Praxair, Germany). During all tests the athletes breathed through a turbine flowmeter and a Hans-Rudolph mask. Heart rate was recorded with a Polar T31 heart-rate belt (1-Hz, Polar Oy, Kempele, Finland). Blood samples (20 \(\mu\)L) for the analysis of blood lactate concentrations were collected from the earlobe in a capillary tube (Eppendorf AG, Hamburg, Germany) at different time points (Figure 1). Blood lactate concentration was analyzed by an amperometric-enzymatic procedure using the Ebio Plus system (Eppendorf AG, Hamburg, Germany). At the same time points, the participants were asked to rate their perceived level of exertion using the 6-to-20 Borg scale.\(^ {25}\)

In addition, the oxygenation of the right vastus lateralis was measured by near-infrared spectroscopy (NIRS) (Portamom, Artinis Medical Systems, Zetten, The Netherlands). Alterations in tissue concentrations of oxy-[\(HbO_2\)], deoxy-[\(HHb\)], and total hemoglobin \([Hb]\) were monitored at wavelengths of 760 and 840 nm with a portable NIRS device attached to the right vastus lateralis, as described elsewhere.\(^ {26}\) The tissue-saturation index (TSI, expressed as \% and calculated as \([HbO_2]/([HbO_2]+[HHb])\)) was used as an indicator of the balance between oxygen supply and consumption.

Statistical Analyses

All statistical tests were carried out with the Statistica software package for Windows (version 7.1, StatSoft Inc, Tulsa, OK, USA). Data are presented as mean ± SD. Repeated-measures analysis of variance was applied to compare each parameter at the different time points and interventions. If global changes over time were identified, Fisher least-significant-difference post hoc analysis was carried out for detection of alpha. An alpha value of \(P < .05\) was considered statistically significant. Differences in \(t_{\text{lim}}\) (Δ R1 vs R2 between WBC and PBO) were analyzed with a Student paired \(t\) test and Cohen \(d\) effect sizes. The thresholds for small, moderate, and large effects were defined a priori as 0.20, 0.50, and 0.80, respectively.\(^ {27}\)

Results

There were no statistical differences in any parameters measured at baseline (R1pre) or after R1 and the fatigue-inducing intense-running protocol (R1pos) between the WBC and PBO interventions. Student paired \(t\) test revealed that the difference in \(t_{\text{lim}}\) between R1 and R2 was lower during the WBC intervention than in the PBO intervention \((P < .05\), effect size \(d = 1.13\), as presented in Figure 2.\(^ {27}\)

Figure 2 — Mean ± SD of time to exhaustion \((t_{\text{lim}})\) in ramp test 1 and ramp test 2 and the change (Δ) between the tests \((t_{\text{lim}} \text{ ramp 1} - t_{\text{lim}} \text{ ramp 2})\) for whole-body cryotherapy (WBC) and placebo intervention (PBO). *Statistically significant differences at \(P < .05\) between the Δ values (WBC vs PBO).
Post hoc analysis showed that longer \( t_{\text{lim}} \) in R2 during the WBC condition was accompanied by higher maximal blood lactate values than in PBO, while \( \text{VO}_2 \) (\( P = .30, d = 0.11 \)), heart rate (\( P = .93, d = 0.02 \)), and RPE (\( P = .80, d = 0.13 \)) showed no statistical differences at maximal level. However, submaximal intensities after WBC revealed lower \( \text{VO}_2 \) at 3.6 m/s (\( P = .02, d = 0.32 \)), lower heart rates at rest (\( P < .01, d = 0.55 \)) and at 3.2 m/s (\( P < .01, d = 0.23 \)), and lower RPE values at all 3 submaximal steps (3.2 m/s, \( P < .01, d = 0.83 \), 3.6 m/s, \( P = .04, d = 0.40 \), 4.0 m/s, \( P = .03, d = 0.41 \)). In addition, TSI of the vastus lateralis muscle was higher at submaximal (3.6 m/s, \( P < .01, d = 0.68 \); 4.0 m/s, \( P < .01, d = 0.81 \)) and maximal level (\( P < .01, d = 1.01 \)) in the WBC condition (Figure 3).

Temperature values and perceptual responses evaluated at 5 different time points (PEPS and EZ Scale, see Figure 1) during the testing procedure are presented in Table 1. \( T_{\text{body}} \) was reduced by 4.5°C (\( P < .01, d = 9.64 \)) after applying WBC and still lower.

Figure 3 — Ramp test 2 values (mean ± SD) for whole-body cryotherapy (WBC) and placebo intervention (PBO) of (A) change (\( \Delta \)) in tissue-saturation index (TSI), (B) rating of perceived exertion (RPE), (C) oxygen consumption, (D) heart rate, and (E) blood lactate concentration. *Statistically significant differences at \( P < .05 \) of the same measurement between WBC and PBO.
Table 1  Body, Skin, and Core Temperature; Lactate; Perceived Physical State (PEPS); and Psychological Strain/Motivational State (EZ 0–5 Scale), Mean ± SD

<table>
<thead>
<tr>
<th>Variable</th>
<th>R1\textsubscript{pre}</th>
<th>R1\textsubscript{post}</th>
<th>Rest\textsubscript{50min}</th>
<th>R2\textsubscript{pre}</th>
<th>R2\textsubscript{post}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PBO</td>
<td>WBC</td>
<td>PBO</td>
<td>WBC</td>
<td>PBO</td>
</tr>
<tr>
<td>Body temperature (°C)</td>
<td>34.6 ± 0.4</td>
<td>34.6 ± 0.3</td>
<td>36.0 ± 0.5</td>
<td>36.0 ± 0.3</td>
<td>35.2 ± 0.3</td>
</tr>
<tr>
<td>Skin temperature (°C)</td>
<td>30.3 ± 0.7</td>
<td>30.3 ± 0.4</td>
<td>30.6 ± 0.8</td>
<td>30.4 ± 0.8</td>
<td>30.7 ± 0.7</td>
</tr>
<tr>
<td>Core temperature (°C)</td>
<td>36.9 ± 0.5</td>
<td>36.9 ± 0.3</td>
<td>39.0 ± 0.4</td>
<td>39.0 ± 0.5</td>
<td>37.6 ± 0.1</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>1.1 ± 0.3</td>
<td>1.0 ± 0.2</td>
<td>9.4 ± 1.6</td>
<td>9.8 ± 2.4</td>
<td>n.d.</td>
</tr>
<tr>
<td>Perceived physical fitness (a.u.)</td>
<td>3.5 ± 0.7</td>
<td>3.7 ± 0.5</td>
<td>2.6 ± 0.8</td>
<td>2.7 ± 0.5</td>
<td>2.8 ± 0.4</td>
</tr>
<tr>
<td>Perceived physical energy (a.u.)</td>
<td>3.6 ± 0.8</td>
<td>4.1 ± 0.8</td>
<td>1.2 ± 0.8</td>
<td>1.2 ± 0.4</td>
<td>1.9 ± 0.9</td>
</tr>
<tr>
<td>Perceived physical flexibility (a.u.)</td>
<td>2.8 ± 0.5</td>
<td>3.0 ± 0.7</td>
<td>2.4 ± 1.0</td>
<td>2.6 ± 1.0</td>
<td>2.4 ± 0.9</td>
</tr>
<tr>
<td>Perceived physical health (a.u.)</td>
<td>4.5 ± 0.3</td>
<td>4.4 ± 0.7</td>
<td>4.1 ± 0.5</td>
<td>3.8 ± 1.0</td>
<td>4.0 ± 0.7</td>
</tr>
<tr>
<td>Perceived sensation of recovery (a.u.)</td>
<td>3.3 ± 0.5</td>
<td>3.3 ± 1.1</td>
<td>2.6 ± 1.1</td>
<td>2.8 ± 1.2</td>
<td>2.0 ± 0.7</td>
</tr>
<tr>
<td>Readiness to strain (a.u.)</td>
<td>3.5 ± 0.9</td>
<td>3.7 ± 0.5</td>
<td>1.9 ± 0.9</td>
<td>2.1 ± 0.7</td>
<td>2.3 ± 0.9</td>
</tr>
</tbody>
</table>

Abbreviations: PBO, placebo intervention; WBC, whole-body cryotherapy intervention; R1, ramp test 1; R2, ramp test 2; a.u., arbitrary units; n.d., not determined.

*Statistically significant differences at $P < .05$ of the same measurement between WBC and PBO.
after R2 than in PBO \((P < .01, d = 0.79)\). At \(R2_{pre}\), \(T_{core}\) was 0.2°C ± 0.3°C lower in the WBC intervention than in PBO \((PBO 37.4°C ± 0.2°C, WBC 37.2°C ± 0.2°C)\). This difference in \(T_{core}\) approached statistical significance \((P = .053)\) and demonstrated a large effect size \((d = 0.86)\).

Post hoc analysis of the psychological questionnaire showed that perceived physical fitness \((P = .04, d = 0.72)\) and energy \((P < .01, d = 0.85)\) were increased after WBC \((R2_{pre})\), as well as recovery \((P < .01, d = 0.95)\) and readiness to strain \((P = .01, d = 0.73)\). However, recovery \((P < .01)\) and readiness to strain \((P < .05)\), as well as perceived physical flexibility \((P = .02)\), were already increased before WBC was applied \((rest_{30min})\).

### Discussion

The aim of the current study was to investigate the effects of WBC (3 min at −110°C) on acute recovery and key variables of endurance performance during high-intensity intermittent exercise. The most striking findings were as follows: (1) In thermoneutral environment conditions, WBC (3 min at −110°C) is able to improve acute recovery of maximal endurance performance \((t_{run})\) with duration of approximately 15 minutes. (2) Cardiorespiratory and perceptual load is reduced during running at submaximal intensities after WBC, indicated by lowered heart rate, \(VO_2\), and RPE compared with PBO. (3) Three minutes of WBC at −110°C lead to a higher oxygenation of the vastus lateralis during subsequent high-intensity exercise compared with PBO.

Recently it was shown that 3 minutes of partial-body cryotherapy (excluding the head) at −110°C enhances recovery of eccentric muscle performance between 2 resistance-training sessions.\(^9\) To the best of our knowledge this is the first study to show that WBC enhances parameters of acute recovery during high-intensity intermittent endurance exercise in thermoneutral climatic conditions, as well. A very important parameter to estimate athletes’ recovery after strenuous exercise is their level of sports-specific maximal-exercise performance\(^{29–30} – t_{run}\) in the current study. Based on the results of the current study WBC appears to enhance the rate of recovery after maximal aerobic performance, indicated by significantly lower change in \(t_{run}\) between R1 and R2 compared with PBO. These findings support and extend the previously published data of Yeargin et al.,\(^11\) who demonstrated comparable CWI-induced improvements in subsequent running performance in the heat. Since it is well documented that exercise performance is reduced once the athlete’s core temperature reaches a critical level of approximately 39°C,\(^{20}\) most precooling studies aimed to reduce \(T_{core}\) to increase the body’s capacity for heat storage and dampen the increase of \(T_{core}\).\(^3\) Therefore, positive effects of cooling treatments on endurance performance were reported, especially when long exercise durations were combined with hot (27–34°C) environmental conditions.\(^{1–13}\)

The current study confirms the hypothesis that WBC (3 min at −110°C) is sufficient to enhance recovery of endurance performance when exercise is conducted in thermoneutral conditions, where \(T_{core}\) will not reach a critical level during exercise. Although it has been shown that precooling is less effective during short-term endurance performance and has almost no effect on endurance performance in moderate ambient conditions,\(^2\) the possibility of WBC enhancing performance itself and not recovery cannot be entirely excluded.

To describe the potential of a cooling protocol, \(T_{core}\) is the most prominent analyzed variable. \(T_{core}\) was 0.2°C ± 0.3°C lower immediately after the application of WBC than with PBO \((R2_{pre})\). The magnitude in the difference of \(T_{core}\) is in line with the literature,\(^{10}\) and the lack of statistical significance is most likely related to type II error \((P = .053)\). Since Costello et al.\(^{10}\) showed that \(T_{core}\) still declined 1 hour after application of WBC, we may assume that the short period of 15 minutes between WBC and the following high-intensity exercise \((R2)\) prevented an even greater reduction of \(T_{core}\) in the current study. The physiological importance of this acute reduction in \(T_{core}\) is also indicated by the large effect size \((d = 0.86)\). In addition, \(T_{skin}\) was significantly reduced immediately after WBC in the current study. Consequently, both variables should be taken into account when the magnitude of a cooling protocol is described. Therefore, use of \(T_{body}\), as it is calculated by the use of both \(T_{core}\) and \(T_{skin}\),\(^2–3\) might be recommended, especially in conjunction with precooling and intercooling protocols that are quickly followed by exercise testing. Immediately after WBC \((R2_{pre})\), \(T_{body}\) was significantly reduced by 4.5°C. It is well documented that reductions in body and tissue temperature cause peripheral vasodilation and reduced peripheral blood flow.\(^8\) This leads to increased central blood volume, blood pressure, and stroke volume, as well as reductions in heart rate to maintain cardiac output.\(^13–14,16\) Heart rate was significantly reduced after WBC at rest and during the first submaximal intensity of R2 compared with PBO. The reduced heart rate in the current study might explain the enhanced performance after WBC by improved cardiac efficiency or less cardiovascular strain at submaximal intensities.\(^14\) In addition, metabolic load was reduced in submaximal intensities after WBC, as well, indicated by lower \(VO_2\). Reduced submaximal \(VO_2\) suggests an increased work economy, with less effort needed to complete submaximal exercise or a lower \(VO_2\) of the passive muscles due to vasodilation and therefore lower blood and oxygen supply, as well. On the other hand, blood and oxygen supply to the working muscles appear to be enhanced after WBC, as an increase in TSI indicates a higher oxygenation status of the vastus lateralis during the entire R2 compared with PBO. This might be explained by improved cardiac efficiency, with vasodilatation only in the working muscles while blood flow to the passive limbs is still depressed.\(^13–16\) Furthermore, WBC stimulates parasympathetic activity, allowing rapid cardiodeceleration and faster recovery,\(^19\) which might be important in the short recovery period applied in the current study.

Notably, the participants’ RPE was significantly reduced during the submaximal stages in the WBC condition compared with PBO. This is in line with the observed reduced cardiometabolic strain and endorsed by the psychological questionnaire, which revealed increased perceived physical fitness and energy, as well as increased recovery and readiness to strain, after WBC. Although it is unlikely that WBC induces analgesia directly by reducing nerve conduction velocity, as skin temperature is not reduced below 13°C,\(^{10}\) psychological-questionnaire and RPE values indicate an acute increase in well-being after WBC and throughout subsequent exercise. As reported previously, WBC increases norepinephrine,\(^3\) which could have had an additional analgesic effect in the current study. In this context Costello et al.\(^3\) and Ferreira-Junior et al.\(^2\) hypothesized that WBC might acutely reduce muscle soreness and the initial muscle damage after exercise, accompanied by reductions in muscle swelling, pain, tenderness, and discomfort, leading to a perceived improved recovery.\(^6\)

Since it is impossible to blind the participants to the recovery method, a psychological effect induced by the WBC condition cannot be excluded. As the psychological dimensions of perceived physical flexibility, recovery, and readiness to strain were already elevated before WBC was applied, the results of the questionnaires may indicate differences in the psychological status, depending on the presence of a recovery treatment. These results support the findings of Hornery et al.,\(^7\) who demonstrated a large placebo effect in halftime cooling via cooling jacket, although the cooling method
was, in contrast to our study, not sufficient to induce significant physiological thermoregulatory effects. However, an improved performance after WBC should be of interest for athletes and coaches, regardless of the underpinning mechanisms. Furthermore, this psychological effect could be described as WBC-altered thermal sensation and anticipation, which are important factors for sports performance as described in a current model of fatigue. This may have also been responsible for the enhanced recovery in the current study, but only in combination with the reduced tissue temperature and the resulting metabolic, cardiorespiratory, and hemodynamic alterations at submaximal intensities.

Finally, none of the athletes reported any injuries or negative side effects related to the cold exposure. We therefore conclude that acute WBC, as applied in the current study, may be administered without health risk in healthy well-trained athletes.

**Practical Applications and Conclusion**

Based on the results of the current study, the most important finding for athletes and coaches is that exposure to very cold air (3 min at −110°C) during 2 bouts of high-intensity exercise improves performance ($P_{max}$) in thermoneutral ambient conditions by a higher oxygenation of the working muscles, as well as lower heart rate, VO$_2$, and RPE values at submaximal intensities and alterations in the athletes’ perceived physical state. Performance improvements might be induced by enhanced blood and oxygen supply to the working muscles, as well as a reduction in cardiovascular strain and increased work economy at submaximal intensities. Improvements in submaximal exercise might be beneficial, especially in team sports and training or competitions that do not require maximal effort alone but consist of tactical elements and submaximal intensities and may be a more feasible means to enhance acute recovery in athletes. However, similar effects on performance and the physiological parameters presented in this WBC study need to be confirmed using CWI in a thermoneutral environment.

**Acknowledgments**

The authors would like to thank the participants who took part in the study and the staff of Bayer 04 Leverkusen Soccer GmbH for their support and granting access to their cryochamber and laboratory.

**References**


24. Nitsch J. Die Eigenzustandsskala (EZ-Skala) - Ein Versuch zur hier-
archisch- mehrdimensionalen Befindlichkeitsskalierung. In: Nitsch J, 
Udris I, eds. Beanspruchung im Sport. Beiträge zur psychologischen 
Analyse sportlicher Leistungssituationen. Bad Homburg, Germany: 
Muscle oxygenation asymmetry in ice speed skaters: not compensated 
27. Cohen J. Statistical Power Analysis for the Behavioral Science. 2nd 
J, Urhausen A. Prevention, diagnosis and treatment of the 
T, Nielsen B. Influence of body temperature on the development 
30. Costello JT, Donnelly AE, Karki A, Selfe J. Effects of whole body 
cryotherapy and cold water immersion on knee skin temperature. Int 
31. Noakes TD. Time to move beyond a brainless exercise physiology: 
the evidence for complex regulation of human exercise performance. 
H10-082