Effects of lymphatic drainage and local cryo exposition regeneration after high-intensive exercises

Michael Behringer¹
Diana Jedlicka¹
Molly McCourt¹
Matthias Ring²
Joachim Mester¹

¹ Institute for Training Science and Sport Informatics, German Sport University Cologne, Germany
² Digital Sports Group, Pattern Recognition Lab, Friedrich-Alexander University Erlangen-Nuremberg, Germany

Corresponding author:
Michael Behringer
Institute for Training Science and Sport Informatics, German Sport University Cologne
Am Sportpark Müngersdorf, 6
50933 Cologne, Germany
E-mail: behringer@dshs-koeln.de

Summary

Background: Recovery from exercise and competition is increasingly important in sports medicine, particularly when rest periods are short. The objective is to determine the efficacy of cryo exposition (CRY) and manual lymphatic drainage (MLD) to hasten short term recovery of muscle performance after eccentric contractions.

Methods: In a randomized controlled trial, 30 healthy sport students (21 males, 9 females; age: 25.7±2.8 years) performed 4×20 eccentric contractions of knee extensors, followed by 30 min MLD, CRY, or rest (RST) under controlled laboratory environment. Maximal voluntary contractions (MVC), electrically induced muscle fatigue (FI), and electrically induced tetani (EIT) at low (T2: 20 Hz) and high frequencies were tested.

Results: Force decline and recovery kinetics regarding MVC, FI, and EIT did not differ significantly (p<0.05) between groups. That is, 24 h after the intervention, MVC (MLD: 80.9±5.5%; CRY: 81.1±8.5%; RST: 83.5±7.3%), FI (MLD: 83.2±23.7%; CRY: 81.2±38.8%; RST: 93.2±22.9%), and EIT (T1: MLD: 53.0±29.5%; CRY: 39.0±32.9%; RST: 46.3±26.1%; T2: MLD: 84.2±27.2%; CRY: 64.2±24.2%; RST: 66.6±22.3%) were similarly depressed irrespective of applied treatments.

Conclusion: Neither CRY nor MLD hastened the recovery of muscle performance, when applied for 30 min. Identification number of the Primary Registry Network: DRKS00007608.

Introduction

Recovery from exercise and competition is increasingly important in sports medicine. This especially holds true for sports in which the interbout rest periods are short. In practice, a broad range of physical agents and modalities are applied to enhance the rate of recovery, although only a minority of these approaches is based on good scientific evidence¹. Some previously published studies in this field of research proposed that increasing blood flow velocity in affected muscle groups (e.g. by light exercise) helps to restore muscle function due to an improved removal of accumulated metabolites from muscle tissue². By contrast, others found that passive recovery in terms of rest and massage reveals beneficial effects³. The aim of the present study was to investigate, if lymphatic drainage and locally applied cryo exposition are capable to enhance short term (24 h) recovery after a single bout of strenuous eccentric exercise. These two frequently applied treatments were selected for the present study because both of them have been suggested to support the physiological recovery process despite partially opposing effects on lymph- and blood flow of treated muscles. More concretely, the lymph flow velocity can be increased by lymphatic drainage up to 8-fold of resting condition, depending on the treatment duration and therapists’...
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experience. In addition, the venous blood flow increases concomitantly, without inducing a reactive hyperemia owing to the low-frequency and pressure of the technique specific handgrips. These effects increase the amount of fluid, which is removed from peripheral tissues per time, resulting in both, an edema reducing effect and an increased clearance of fatty acids, white blood cells, and muscle enzymes from the extracellular space. The latter is supported by a previously published meta-analysis that reported beneficial effects of the lymphatic drainage on serum enzyme levels in patients with acute skeletal muscle cell damage as well as reduction of edema after sprains and bone fractures.

By contrast, low temperatures decrease the lymph-flow significantly during the cooling process, followed by a rebound of lymph-flow velocity with rewarming, as shown in animal models. Similarly, arterial and venous blood flow are reduced, when cryotherapy is applied. However, there are some controversies regarding the type of vasodilation that follows the intense vasoconstriction. While some reported a cyclic response consisting of alternating dilation and constriction, others reported a slow and steady vasodilation. Nevertheless, cryotherapy is used for rehabilitation of sports-injuries and overuse symptoms, and to hasten recovery between training and competition sessions. The regenerating potential of cryotherapy is thought to be based on analgesic, anti-swelling, anti-inflammatory, relaxing, as well as overall rejuvenating effects leading to a decrease in skin and tissue temperature. Hauswirth et al. found a better muscle strength output and positive effects on perceived tiredness or pain in well-trained runners after a damaging trail run simulated on a motorized treadmill after cryo exposition.

Therefore, the primary aim of the present study was to investigate if the frequently applied local cryo exposition and the manual lymphatic drainage are capable of enhancing short-term recovery. The results of the present study may help sport medicine specialists and physical therapists to improve their treatment strategies.

Materials and methods

Subjects

In this randomized controlled study a total of 35 male and female sport students were recruited as a sample of convenience from our University. Five participants were excluded as they presented exclusion criteria, defined as injuries of the musculoskeletal system within 6 months prior to the study or any cardiovascular and metabolic diseases. All participants were engaged in at least two hours of physical activity per week at enrollment. To avoid interference from other activities on muscle performance, subjects were instructed to refrain from intense or prolonged physical activity three days prior to and 24 h post intervention. To further standardize individual activity levels, subjects were asked to wear a step counter (Omron, step counter walking style III, OMRON Healthcare Europe B.V, Hoofddorp, Netherlands) and to take 5000-10000 steps between 1 h and 24 h post exercise, corresponding to an activity level rating from “low” to “somewhat active”.

By drawing lots, included subjects were randomly assigned to a manual lymphatic drainage group (MLD, n = 11), a cryo exposition group, (CRY, n = 11), or a control group (RST, n = 8) (Fig. 1). To reduce interference from subjects’ hydration status fluid intake (not further specified) of 20-25 ml/ kg body weight was recommended (2 ml/ kg body weight within the 1st h following the exercise protocol, 5ml/ kg body weight from the 2nd to the 4th h and 15-18 ml/ kg body weight within the remaining 20 h). Subjects were instructed to refrain from food consumption two hours prior to the onset of pre-test measuring procedures. The study was approved by the local ethics committee of the German Sport University Cologne and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Further, the present study meets the ethical standards of the journal as laid down in the editorial published by Padulo et al. All subjects provided informed written consent prior to participation in the study. Two weeks prior to the intervention, subjects were invited to the laboratory to get familiarized with the training and testing procedures. However, subjects were only allowed to perform the planned exercise protocol with a light resistance in order to avoid blunted responses of tested parameters in terms of a repeated bout effect.

Exercise protocol

The intervention consisted of 4x20 repetitions on a knee extensor machine (Edition Line, gym80 International, Gelsenkirchen, Germany) with 1 min rest be-
资本市场可用的肌刺激器（Compex 3 Professional）

用于EIT和FI的电气刺激

肌电诱导的抽搐（EIT）和疲劳指数（FI）

干预协议。

最大自愿收缩（MVC）

根据EIT和FI测量的前（pre），立即以及之后（post），以及1 h，4 h，和24 h后，对实验条件的整体差异进行了分析。在相同的时间段内，使用分析方差（ANOVA）方法进行统计分析。

电刺激诱导的抽搐（EIT）和疲劳指数（FI）

对于EIT和FI期间的电刺激，使用了商用的myostimulator（Compex 3 Professional Stimulator/ mi-sensor System, Freiburg, Germany）和自粘性刺激性凝胶电极（Dura-Stick plus, DJO Global, Vista, USA）。

结果

没有参与者的参与受到伤害或退出研究期间（Fig. 1）。统计分析结果揭示了

电刺激期间，对于四不同的电刺激模式的力响应，每种模式的刺激强度设置为60 Hz, 400 µs，以及0.5（2 s on, 2 s off），分别。力数据由测量-数据管理软件Digi Max（Mechatronic, Hamm, Germany）以100 Hz的采样频率采集。

统计分析

总体差异分析

电刺激期间，力响应对于四个不同的电刺激模式的试验和对照组之间的时间差异进行了详细分析。这些分析是在符合正态分布的条件下进行的。

试验

电刺激期间，force response to four different electrical stimulation modes, group × time. Where significant F values were identified, the post-hoc Bonferroni test was used for a more detailed analysis of differences between treatment means. These analyses were performed with Statistica (Statistica for Windows, 7.0, Statsoft, Tulsa, OK). An a priori estimation of the required sample size for the repeated measures ANOVA (within-between interaction) using G*Power 3.1.3 (University Kiel, Germany) revealed a total sample size of n = 27. The following input parameters were used: effect size f = 0.25, alpha error probability = 0.05, power = 0.8, number of groups = 3, number of measurements = 5, correlation among repeated measures = 0.5, nonsphericity correction = 1. All data are expressed as mean ± standard deviation of the mean. Statistics with a value of p < 0.05 were considered significant.
that the data met the assumption of normality. Anthropometric values did not differ between the three groups investigated (Tab. I). Further, no pre-test differences between groups were present for EIT, FI and MVC force (Fig. 2). The mean step count was 7179.7±2029.0, 7348.3±3009.3, 7042.7±3488.7 for MLD, CRY, and RST, respectively. Room temperature (23.0±1.6°C) and humidity (33.8±6.9%) remained fairly constant over all measurement time points. Surface temperature from the gel cool packs, measured by thermal imaging, increased from -16.8±1.8°C at pre to -9.9±0.5°C at post test. When covered by the cotton harness, a temperature of 1.9±0.5°C and -0.1±0.4°C was measured at pre and post test, respectively. The skin temperature of the treated thighs in CRY changed from 30.6±0.9°C pre - to 20.4±2.1°C at post test, while they remained constant for MLD and RST (pre: 30.3±1.1°C; post: 30.8±1.1°C).

The applied current during EIT was 27.95±3.99 mA, 25.46±3.93 mA, and 29.37±8.56 for MLD, CRY, and RST, respectively. Irrespective of frequency (100 Hz vs. 20 Hz), EIT force level were significantly reduced in all groups immediately following the eccentric exercise protocol, but recovery kinetics did not differ as a function of applied treatments (Tab. II, Fig. 2). In none of the analyzed groups, an interaction between stimulation frequency and time was observed, indicating that prolonged force depression was not limited to low stimulation frequencies. Similarly, force measured during MVC tests at post-test was significantly reduced (Fig. 2, Tab. III). However, the force of these voluntary contractions did not recover in the time course of follow-up measurements regardless of the applied treatment and no significant group by time interaction was found. Fatigue rate of exercised muscles, measured as FI, was not affected by the present protocol (Fig. 2, Tab. III). The applied current during the FI tests were the same as for the EIT tests.

Discussion

Statement of principal findings

This study was designed to compare the effects of two different treatment modalities on the recovery of muscle performance after a bout of eccentric contrac-

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age [yrs]</th>
<th>Height [cm]</th>
<th>Body weight [kg]</th>
<th>Body Fat [%]</th>
<th>Distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLD</td>
<td>11</td>
<td>26.5 ± 2.9</td>
<td>175.8 ± 6.8</td>
<td>71.4 ± 8.8</td>
<td>16.3 ± 6.3</td>
<td>5.3 ± 1.7</td>
</tr>
<tr>
<td>CRY</td>
<td>11</td>
<td>26.1 ± 3.0</td>
<td>180.7 ± 9.4</td>
<td>78.6 ± 9.3</td>
<td>13.5 ± 5.2</td>
<td>5.9 ± 3.6</td>
</tr>
<tr>
<td>RST</td>
<td>8</td>
<td>24.0 ± 1.7</td>
<td>180.8 ± 10.1</td>
<td>75.5 ± 16.1</td>
<td>11.7 ± 3.8</td>
<td>6.8 ± 4.3</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>25.7 ± 2.8</td>
<td>178.9 ± 8.8</td>
<td>75.1 ± 11.4</td>
<td>14.0 ± 5.5</td>
<td>5.9 ± 3.2</td>
</tr>
</tbody>
</table>

MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest

Figure 2. Mean force generated by the quadriceps femoris, when stimulated with 2 s tetani at 100 Hz (T1) (A); mean force generated by the quadriceps femoris, when stimulated with 2 s tetani at 20 Hz (T2) (B); mean force generated by the quadriceps femoris in percent of baseline value, when maximally voluntarily contracted (MVC) (C). Time point measurements were before (pre), immediately after (post), as well as 1 h, 4 h, and 24 h after the eccentric exercise protocol (CRY, circles; MLD, squares; RST, triangles).
The fact that the generated force during MVC and the majority of EIT tests were significantly (p < 0.05) reduced immediately after the eccentric knee extensions until the 24 h measurement indicates that the chosen protocol resulted in a prolonged muscle fatigue. However, the tested physical agent (CRY) and modality (MLD), did not affect the rate of recovery of the knee extensors following the performed bout of eccentric contractions. Further, the force response to low-frequency stimulation (T2) was more affected by the applied protocol than that to high-frequency stimulation (T1). This is a well-known feature of a long-term force depression and is assumed to reflect that low frequencies are at the steep part of the force-calcium relationship, which are therefore more susceptible to reduced myofibrillar calcium sensitivity and/or tetanic calcium concentrations19.

Interestingly, the ratio between the mean force of the 15th and the 1st tetanus of performed fatigue runs was virtually unaffected by the present investigation. More precisely, irrespective of group or measurement time point, force dropped about 40- 60% from the 1st to the 15th tetanus. However, it needs to be taken into account that similar to the results presented for T1 and T2, the force of the first tetanus of the fatigue runs was significantly reduced after the exercise protocol.

### Table II. Mean values and standard deviations of EIT tests (absolute values).

<table>
<thead>
<tr>
<th>Group</th>
<th>pre</th>
<th>post</th>
<th>1 h</th>
<th>4 h</th>
<th>24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1 [N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLD</td>
<td>126.6 ± 42.8</td>
<td>55.6 ± 41.8*</td>
<td>63.9 ± 29.1*</td>
<td>79.5 ± 32.6*</td>
<td>106.3 ± 41.0*</td>
</tr>
<tr>
<td>CRY</td>
<td>137.7 ± 56.7</td>
<td>60.6 ± 29.3*</td>
<td>67.3 ± 34.1*</td>
<td>84.5 ± 82.1</td>
<td>80.5 ± 35.0</td>
</tr>
<tr>
<td>RST</td>
<td>145.6 ± 36.3</td>
<td>61.8 ± 36.2*</td>
<td>91.0 ± 39.2</td>
<td>92.0 ± 33.0</td>
<td>99.0 ± 45.2</td>
</tr>
<tr>
<td>Total</td>
<td>135.8 ± 46.0</td>
<td>59.1 ± 34.9</td>
<td>72.4 ± 34.6</td>
<td>84.7 ± 54.6</td>
<td>94.9 ± 40.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>post</th>
<th>1 h</th>
<th>4 h</th>
<th>24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T2 [N]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLD</td>
<td>73.9 ± 31.5</td>
<td>12.2 ± 16.7*</td>
<td>24.4 ± 18.9*</td>
<td>26.0 ± 16.3*</td>
</tr>
<tr>
<td>CRY</td>
<td>93.9 ± 35.3</td>
<td>18.6 ± 15.7*</td>
<td>28.6 ± 21.9*</td>
<td>27.3 ± 27.8*</td>
</tr>
<tr>
<td>RST</td>
<td>92.5 ± 21.1</td>
<td>26.0 ± 14.6*</td>
<td>40.5 ± 27.1*</td>
<td>38.8 ± 20.9*</td>
</tr>
<tr>
<td>Total</td>
<td>86.2 ± 31.1</td>
<td>18.2 ± 16.2</td>
<td>30.2 ± 22.6</td>
<td>29.9 ± 22.2</td>
</tr>
</tbody>
</table>

EIT: Electrically induced tetani, MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest. Stars (*) represent time effects in reference to the pre measurement time point, pound key (#) represent group effects.

### Table III. Mean values and standard deviations of MCV (absolute values) and FI tests (percent value).

<table>
<thead>
<tr>
<th>Group</th>
<th>pre</th>
<th>post</th>
<th>1 h</th>
<th>4 h</th>
<th>24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MVC [N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLD</td>
<td>917.3 ± 232.1</td>
<td>712.1 ± 179.9*</td>
<td>710.0 ± 189.6*</td>
<td>717.5 ± 176.0*</td>
<td>740.6 ± 190.1*</td>
</tr>
<tr>
<td>CRY</td>
<td>965.5 ± 234.1</td>
<td>742.8 ± 166.4*</td>
<td>757.1 ± 184.1*</td>
<td>776.7 ± 187.4*</td>
<td>794.1 ± 241.8*</td>
</tr>
<tr>
<td>RST</td>
<td>947.7 ± 379.8</td>
<td>834.3 ± 242.0*</td>
<td>800.1 ± 206.5*</td>
<td>832.6 ± 227.3*</td>
<td>850.9 ± 254.3*</td>
</tr>
<tr>
<td>Total</td>
<td>966.8 ± 273.1</td>
<td>755.9 ± 193.2</td>
<td>751.3 ± 188.9</td>
<td>742.5 ± 219.9</td>
<td>789.6 ± 224.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>FI [%]</th>
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</tr>
</thead>
<tbody>
<tr>
<td>MLD</td>
<td>51 ± 14</td>
<td>44 ± 28</td>
<td>57 ± 21</td>
<td>56 ± 22</td>
<td>44 ± 22</td>
</tr>
<tr>
<td>CRY</td>
<td>59 ± 0.11</td>
<td>53 ± 0.14</td>
<td>38 ± 20</td>
<td>41 ± 21</td>
<td>55 ± 16</td>
</tr>
<tr>
<td>RST</td>
<td>57 ± 13</td>
<td>61 ± 16</td>
<td>60 ± 17</td>
<td>60 ± 4</td>
<td>56 ± 18</td>
</tr>
<tr>
<td>Total</td>
<td>56 ± 12</td>
<td>56 ± 12</td>
<td>52 ± 21</td>
<td>52 ± 18</td>
<td>52 ± 18</td>
</tr>
</tbody>
</table>

MLD: Manual lymphatic drainage, CRY: Local cryo exposition, RST: Rest. Stars (*) represent time effects in reference to the pre measurement time point.
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Therefore, FI data from repeated short tetani indicate that the rate of force decline was similar at all measurement time points, though the absolute force values were reduced.

**Strengths and weaknesses of the study**

To the best knowledge of the Authors, this is the first study to investigate the effects of the commonly applied MLD and CRY on recovery after eccentric contractions. The main strength of the present investigation lies in the combination of voluntary (MVC force) and involuntary measures (FI) of muscle performance, which allows for a robust estimation of the effect of the applied MLD and CRY on muscle recovery. Further, we tried to improve data accuracy and reliability by having the same experienced physiotherapist applying all treatments and performing all measurements at all time points. By contrast, one of the limitations of the present study was the short follow-up time of 24 h after the intervention. Thus we possibly missed effects that occurred thereafter. For example, Poumot et al. reported that whole-body cryotherapy exerted effects on the inflammatory response at least up to 96 h after a simulated trail running race, as evident from selected biomarkers. However, the main focus of the present study was to investigate if MLD or CRY are able to improve the short-term recovery of muscle performance after strenuous exercises, which becomes increasingly important in many sports. By contrast, we did not assess any biomarkers. Though biomarkers cannot replace muscle performance tests they may help to estimate the amount of muscle damage, systemic inflammation, and immune cell mobilization. Previous data indicate that the response of such biomarkers is particularly high, when the performed exercise is unaccustomed, prolonged, and includes eccentric contractions. For example, the muscle damage marker creatine kinase has been reported to significantly increase after unilateral eccentric knee extensions to values of 680.4±594.0 IU·L⁻¹. Therefore, we believe that the applied protocol of the present study differs from sport specific training programs and competitions in professional sports. Therefore, the observed results cannot be easily transferred to professional sports. Nevertheless, we believe that the results are important for a better understanding about the potential of the applied treatments to hasten the recovery from exercise induced muscle damage.

**Strengths and weaknesses in relation to other studies, discussing particularly any differences in results**

The force response to low-frequency stimulation (T2) was more affected than that to high-frequency stimulation (T1). However, we found that recovery kinetics of 100 Hz tetani (T1) did not significantly differ from that of 20 Hz tetani (T2). This stays in contrast to the data presented by Edwards et al., who reported that the response to high-frequency stimulation is virtually unaffected following different fatiguing protocols, while low-frequency stimulation presents a long-lasting force decline.

Schillinger et al., who examined the influence of MLD on serum levels of muscle enzymes following endurance treadmill exercise, found a faster reduction in enzymes such as glutamic-oxaloacetic transaminase (GOT) and LDH in subjects that were treated twice for 45 min with MLD. The Authors concluded that this may indicate an improved regeneration after muscle damage. Similarly, MLD was shown to significantly affect the lactate concentration in blood, when compared with classical massage techniques. However, serum levels of muscle proteins and other biomarkers may have resulted in a more complete picture. Another weakness of the study may be that the respective treatments were applied for only 30 min. As outlined above, this was adopted in accordance with the common intervention periods in practice and current guidelines of treatment recommended and followed in German physiotherapy. However, longer intervention durations might have shown different results. Further, it needs to be taken into account that the applied protocol of the present study differs from sport specific training programs and competitions in professional sports. Therefore, the observed results cannot be easily transferred to professional sports. Nevertheless, we believe that the results are important for a better understanding about the potential of the applied treatments to hasten the recovery from exercise induced muscle damage.
ized controlled trials found a positive impact on functional parameters, the vast majority of identified studies failed to support these findings. Nevertheless, it should be taken into account that the gentle rhythmical movements applied by the MLD acting on lymphatic system substantially differs from other massage techniques, making a direct comparison to the present data impossible. When compared to MLD, the role of CRY in enhancement of recovery has been more frequently addressed in literature. However, the results are far from homogeneous. Crystal et al. investigated the effects of a 20 min ice bath (5°C) on muscle recovery after a 40 min downhill run (-10%) and found that the treatment was ineffective at attenuating strength loss and DOMS after muscle-damaging exercise. Similarly, Pointen et al. reported that CRY had no effect on muscle performance following 6 x 25 maximal concentric and eccentric contractions of knee extensors in ten resistance-trained males. But in contrast to the study presented by Crystal et al., Pointen et al. found positive effects on DOMS following CRY. Further, Costello et al. reported that whole-body cryotherapy did not lessen muscle damage following eccentric muscle contractions. While these studies failed to find positive CRY effects on muscle recovery, the study presented by Hausswirth et al. found both enhanced recovery of muscle strength and perceived sensations (i.e. pain, tiredness, and well-being) following a muscle damage protocol on a motorized treadmill. However, due to the within-subject design of that study, the data was largely affected by the well-known repeated bout effect, making a comparison among different treatments in nine subjects debatable. Further, the applied whole-body cryotherapy may have elicited additional systematic changes, like core temperature reduction and cardiovascular or endocrine changes potentially responsible for the outcome. According to two previously published reviews there is some evidence to suggest that cryotherapy may hasten the return to participation and decreases the pain that is associated with soft tissue injury. Nevertheless, both reviews concluded that the quality of available trials in that field of research is poor and that high-quality studies are needed to provide evidence based guidelines for the application of cryotherapy. The effect of cooling on performance recovery of trained athletes was also subject of a recently published meta-analysis of 21 relevant, peer-reviewed randomized controlled trials. It turned out that the average effect of cooling on recovery was small (Hedges’ g = 0.28), but the weighted average 2.4% increase in performance may be large enough for competitive athletes under appropriate conditions. The greatest effect sizes were reported for sprint performance (g = 0.69), whereas effects on strength were distinctly lower (g = 0.1). Interestingly, the effects were greatest when evaluated 96 h after the exercise. Further, cold water immersion (g = 0.34) and cryogenic chambers (g = 0.25) were found to be most efficacious among the various cryotherapy methods.

The effect of CRY via cooling packs reached an effect size close to zero (g = -0.07). Therefore, the selected CRY method, in combination with the short follow-up period, likely explains the missed group-by-time interactions of the present study. When compared to pretest values, the slight insignificant reduction in FI values as a response to CRY 1 and 4 h after the exercise protocol, may be interpreted as a result of a delayed clearance of metabolites from the muscle cells. This is somewhat supported by the fact that the FI values increased at these early time points in MLD, where metabolite clearance was likely increased due to increased lymph flow. However, the present results leave this assumption to be highly speculative.

Meaning of the study: possible mechanisms and implications for clinicians or policymakers

Effective treatment modalities that enhance the rate of recovery after strenuous exercises not only improve the performance for the next of closely spaced competitions, but may also help to prevent fatigue related injuries. Despite the reputed benefits and frequent use CRY and MLD in praxis, the efficacy of these treatments for short term recovery could not be confirmed, when applied for only 30 min. This outcome is important for sport medicine specialists and physical therapists who design recovery strategies for athletes. That is, other treatment strategies than those tested by the present study should be applied to improve the rate of recovery after strenuous exercises.

Unanswered questions and future research

The mechanisms for the contradictory results concerning the high- and low-frequency stimulation (T1, T2) remain unclear and were beyond the scope of the present investigation. Further studies are needed to investigate if longer therapy durations (>30 min) are able to hasten recovery or if longer time point measurements beyond 24 h post exercise show different results. Also following investigations should include additional blood values such as creatine kinase or myoglobin as well as validated psychological questionnaires that measure the perceived discomfort, sleeping quality and well-being and VAS pain values. Urine concentration might be examined prior to the start of the study to determine the hydration status. To assess the general effects of MLD it is as well reasonable to create another group receiving MLD without any physical exercise before.

Conflict of interests

The Authors have no financial involvement and have no conflicts of interest.
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References


