Bringing Light Into the Dark: Effects of Compression Clothing on Performance and Recovery

Dennis-Peter Born, Billy Sperlich, and Hans-Christer Holmberg

To assess original research addressing the effect of the application of compression clothing on sport performance and recovery after exercise, a computer-based literature research was performed in July 2011 using the electronic databases PubMed, MEDLINE, SPORTDiscus, and Web of Science. Studies examining the effect of compression clothing on endurance, strength and power, motor control, and physiological, psychological, and biomechanical parameters during or after exercise were included, and means and measures of variability of the outcome measures were recorded to estimate the effect size (Hedges $g$) and associated 95% confidence intervals for comparisons of experimental (compression) and control trials (noncompression). The characteristics of the compression clothing, participants, and study design were also extracted. The original research from peer-reviewed journals was examined using the Physiotherapy Evidence Database (PEDro) Scale. Results indicated small effect sizes for the application of compression clothing during exercise for short-duration sprints (10–60 m), vertical-jump height, extending time to exhaustion (such as running at $VO_{2\text{max}}$ or during incremental tests), and time-trial performance (3–60 min). When compression clothing was applied for recovery purposes after exercise, small to moderate effect sizes were observed in recovery of maximal strength and power, especially vertical-jump exercise; reductions in muscle swelling and perceived muscle pain; blood lactate removal; and increases in body temperature. These results suggest that the application of compression clothing may assist athletic performance and recovery in given situations with consideration of the effects magnitude and practical relevance.

Keywords: blood flow, cardiac output, heart rate, muscle damage, oxygen uptake, oscillation, venous hemodynamics

In the past 2 decades, various forms of compression clothing have been used by elite and recreational athletes. In running\(^1,2\) and cycling,\(^3,4\) lower body compression clothing such as knee-high socks, shorts, and full-length tights are the most common types of compression garments. To improve hemodynamics, “graduated compression” with pressure decreasing from distal to proximal is recommended.\(^5\) Upper- or full-body compression is applied in various sports to improve maximal strength and power, such as bench-press exercises\(^6\) and throwing performance in cricket players.\(^7\)

The increasing popularity of compression clothing in different sports is likely due to accumulating evidence of enhanced performance\(^1,8\) and recovery.\(^9-11\) Performance in maximal strength and power tasks, such as vertical jumping, has been shown to improve with the application of compression clothing; this is possibly due to increased proprioception and reduced muscle oscillation.\(^8\) However, endurance exercise such as submaximal running seems to be unaffected,\(^2,12\) even if compression clothing has been shown to improve venous hemodynamics\(^13\) and increase deeper-tissue oxygenation\(^14\) and the clearance of metabolites.\(^15\) From a thermoregulatory point of view, compression clothing has been shown to increase muscle temperature,\(^16\) potentially by reducing skin blood flow.\(^17\)

Currently, there has been 1 review summarizing the findings of the application of compression clothing for exercise and recovery, and its conclusions were based mostly on the statistically significant results in the reviewed articles.\(^18\) That review also concludes that there are some isolated indications for physical and physiological effects, including attenuation of muscle oscillation, improved joint awareness, perfusion augmentation, and altered oxygen use at submaximal intensities, whereas the effects of compression clothing on indicators of recovery performance remain inconclusive.

The practical application of statistical significance when comparing the findings of compression and non-compression conditions is open to discussion since it may be influenced by sample size and data variance. By increasing the number of participants, and decreasing variance, statistical significance will be achieved when comparing an experimental and a control trial.\(^19\) Therefore, it seems more relevant to calculate effect sizes
(ESs) to compare and quantify the various findings and detect the practical meaningfulness of the application of compression clothing. When findings are based on individual studies and transferred to general statements, the focus moves to their practical relevance instead of relying solely on statistical significance.19 The approach using Hedges’ g was shown to optimize calculation of the ES by using a pooled standard deviation of both groups, hence standardizing mean differences.20 This quantitative approach has been implemented in other systematic reviews in exercise science.21–23

In general, the heterogeneity of test procedures, with differing types and amounts of compression, makes it difficult to perform a comparison between different studies evaluating compression clothing in an athletic population. Our intent was to review the literature to identify possible benefits of compression clothing for performance and recovery.

The aims of this systematic review regarding the application of compression clothing for performance and recovery were to summarize results from existing data; identify the benefits for endurance and strength, as well as power and motor control; quantify effects on physiological, psychological, and biomechanical parameters; identify possible underlying mechanisms for observed results; and provide recommendations for athletes and consumers.

**Methods**

**Data Sources**

A computer-based literature research was performed during July 2011 using the electronic databases PubMed, MEDLINE, SPORTDiscus, and Web of Science. In addition, the reference lists from these articles and previously known cases were cross-referenced for further relevant studies. The following key words were used to retrieve pertinent articles: athlete, balance, blood flow, blood lactate, compression clothing, endurance, exercise, fatigue, garments, heart rate, muscle damage, pain, swelling, oscillation, oxygenation, oxygen uptake, performance, perceived exertion, power, proprioception, recovery, strength, stroke volume, textiles, thermoregulation, time to exhaustion, and time trial.

**Study Selection**

Peer-reviewed studies were included if they investigated any kind of compression clothing in relation to endurance (n = 15), strength (n = 3), power (n = 8), or both endurance and power (n = 5) during or after exercise. The studies had to assess physiological, biomechanical, or psychological parameters during and/or after exercise. Only studies that presented absolute data as means and measures of variability for the calculation of ESs from an experimental (compression) and a control group (noncompression) were included. Finally, the research must have been conducted on participants without any cardiovascular, metabolic, or musculoskeletal disorders (Figure 1).

**Quality Assessment**

Each study meeting the inclusion criteria was addition-
ally evaluated with the Physiotherapy Evidence Database (PEDro) Scale by 2 independent reviewers.24 On the PEDro scale an item answered with “yes” adds 1 point to the score and “no” contributes 0 points, with a maximum of 10 points. This method has been used in previous systematic reviews for the methodological quality assessment of studies.25–27

**Statistical Analysis**

To compare and quantify the various findings of performance and recovery, ESs for each study were determined as proposed by Glass.28 For each parameter, the ES (Hedges’ g) and associated 95% confidence interval were calculated. Hedges’ g was computed using the difference between means of an experimental (compression) and control (noncompression) group divided by the average baseline standard deviation.20 To optimize ES calculation and estimate the standard deviation for Hedges’ g, baseline standard deviations of experimental and control groups were pooled.20 According to standard practice, the ESs were then defined as trivial (<.10), small (.10–.30), moderate (.30–.50), or large (.50).19 All statistical analyses were carried out using MedCalc, version 11.5.1.0 (MedCalc, Mariakerke, Belgium).

**Results**

Of the initial 423 studies identified, 31 studies were examined using the PEDro score, with an average score of 6.1, ranging from 5 to 9 (maximum possible score = 10 points).

The characteristics of the participants and the compression clothing, measured parameters, and the protocols for each study are summarized in Table 1. The calculated ESs relating to the effects of applying compression clothing for exercise and performance and/or recovery are presented in Figures 2 and 3.

The sample sizes (n = 5–21), age (19–39 y) and gender of the participants (male n = 22, female n = 3, mixed gender n = 5, no gender information n = 1), and type of compression clothing (shirts n = 2, tights n = 14, stockings n = 2, shorts n = 3, knee-high socks n = 9, whole-body compression consisting of tights and a shirt n = 4) that were applied in the reviewed studies showed a high variability (Figure 4).

Only 11 studies included elite or well-trained subjects, while 20 included recreational athletes or participants competing at a regional level. Overall, 16 studies used a graduated compression, with pressure decreasing from distal to proximal. Moreover, 19 studies provided data including the amount of exerted pressure ranging from 8 to 40 mmHg, whereas 12 studies reported no data (Table 1).

**Exercise and Performance**

Altogether, the ES results indicate that compression clothing had either small positive or no effects on performance during exercise. While maximum oxygen uptake was
not affected (ES = 0.08, Figure 2),1,4,15,29–32 performance during maximal endurance exercise such as time to exhaustion (Table 1)29–36 and time-trial performance (3–60 min)2,15,37 indicated small positive effects (ES = 0.15). In addition, endurance-related parameters such as submaximal oxygen uptake (ES = 0.01),2,29,32,36,38 blood lactate concentration during continuous exercise (ES = –0.04),2–4,7,29,31,32,36–40 blood gas such as saturation2–4,7,29,31 and partial pressure of oxygen (ES = 0.01),7,29 and cardiac parameters including heart rate,2,32,37,38,40 cardiac output, cardiac index, and stroke volume (ES = –0.08)2 were not affected by the application of compression compared with noncompression clothing.

Small positive ESs (ES = 0.12, Figure 2) were detected for improvements in single and repeated sprinting (10–60 m),7,16,30,39,41 as well as vertical jumping (ES = 0.10),30,37,39,42 in participants wearing compression clothing. Peak leg power measured on a cart dynamometer16 and performance during maximal-distance throwing7 were not affected by compression clothing (ES = 0.00). In addition, there were no effects on balance, joint-position sense,30 or arm tremble during bench press6 (ES = –0.02).

No mean effects were observed for changes in the perceived exertion during or immediately after exercise (ES = 0.05, Figure 2)1,7,12,29,37,38,41 when compression clothing was applied.
Table 1  Studies Investigating the Effect of Compression Clothing on Performance and Recovery Enhancement

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample size, gender, age (y)</th>
<th>Athletic category</th>
<th>Characteristics of Compression Clothing</th>
<th>Study protocol (occasion when compression clothing was applied)</th>
<th>Effects of compression clothing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ali et al(^37)</td>
<td>12, M+F, 33 ± 10</td>
<td>Competitive runners (VO(_{2\text{max}}) 68.7 ± 6.2 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Socks (G)</td>
<td>10-km TT (during exercise)</td>
<td>TT↓↑, LA↓, CP↑↓, jump↑↓, RPE↑↓, VO(<em>{2\text{max}})↑↓, TTE↑↓, VO(</em>{2\text{max}})↓↑, LA↓, CP↑↓,</td>
</tr>
<tr>
<td>Dascombe et al(^38)</td>
<td>11, M, 28 ± 10</td>
<td>Well-trained runners and triathletes (VO(_{2\text{max}}) 59.0 ± 6.7 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Tights (G)</td>
<td>Incremental running test and TTE at 90% VO(<em>{2\text{max}}), Temp(</em>{\text{amb}}): 22°C ± 2°C (during exercise)</td>
<td>VO(<em>{2\text{max}})↑↓, TTE↑↓, VO(</em>{2\text{max}})↓↑, LA↓, CP↑↓,</td>
</tr>
<tr>
<td>Sperlich et al(^39)</td>
<td>15, M, 22 ± 1</td>
<td>Well-trained runners and triathletes (VO(_{2\text{max}}) 70.4 ± 6.1 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Socks (G)</td>
<td>45-min treadmill running at 70% of VO(_{2\text{max}}) (during exercise)</td>
<td>VO(_{2\text{max}})↑↓, LA↓, CP↑↓,</td>
</tr>
<tr>
<td>Ali et al(^40)</td>
<td>10, M, 36 ± 10</td>
<td>High-performance runners and triathletes (VO(_{2\text{max}}) 70.4 ± 6.1 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Socks (G)</td>
<td>40-min treadmill running at 80% VO(_{2\text{max}}) (during exercise)</td>
<td>VO(_{2\text{max}})↑↓, LA↓, CP↑↓,</td>
</tr>
<tr>
<td>Cabri et al(^41)</td>
<td>6, M, 31 ± 7</td>
<td>Trained runner (5000-m best time 1445 ± 233 s)</td>
<td>Socks</td>
<td>Submaximal run (5000 m) at a velocity of 85% of the 5000-m best time (during exercise, 2 min after)</td>
<td>La↑↓, CP↑↓</td>
</tr>
<tr>
<td>Duffield et al(^42)</td>
<td>11, M, 21 ± 3</td>
<td>Regional rugby players (3–4 training sessions/wk and 1 game/wk)</td>
<td>Tights</td>
<td>Intermittent sprinting: 10 min (1 × 20-m sprint and 10 squat jumps/min; during exercise, 24 h after)</td>
<td>La↑↓, jump↑↓, sprint↑↓, DOMS↑, CK↑↓, damage marker↑↓, HR↓↑, pH↑</td>
</tr>
<tr>
<td>Goh et al(^43)</td>
<td>10, M, 29 ± 10</td>
<td>Recreational runners (VO(_{2\text{max}}) 58.7 ± 2.7 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Tights (G)</td>
<td>20 min at 1st ventilatory threshold followed by run to exhaustion at VO(_{2\text{max}}) at 10°C and 32°C (during exercise)</td>
<td>TTE↑</td>
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<tr>
<td>Jakeman et al(^44)</td>
<td>8, F, 21 ± 2</td>
<td>Physically active (&gt;3 times/wk)</td>
<td>Tights (G)</td>
<td>Intermittent jumping: 10 × 10 drop-jumps (1 jump/10 s) with 1-min rest between sets (compression 12 h after exercise)</td>
<td>CK↑↓</td>
</tr>
<tr>
<td>Jakeman et al(^45)</td>
<td>8, F, 21 ± 2</td>
<td>Physically active (&gt;3 times/wk)</td>
<td>Tights (G)</td>
<td>Intermittent jumping: 10 × 10 drop-jumps (1 jump/10 s) with 1-min rest between sets (compression 12 h after exercise)</td>
<td>CK↑↓</td>
</tr>
<tr>
<td>Kraemer et al(^46)</td>
<td>20, M+F; 23 ± 3</td>
<td>Resistance-trained (&gt;2 y)</td>
<td>WBC</td>
<td>Barbell resistance-training workout: 8 exercises, 3 × 8–10-RM with 2- to 2.5-min rest between sets (compression 24 h after exercise)</td>
<td>DOMS↑</td>
</tr>
<tr>
<td>Rimaud et al(^47)</td>
<td>8, M, 27 ± 1</td>
<td>Trained athletes (VO(_{2\text{max}}) 53.3 ± 2.7 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>Socks (G)</td>
<td>Incremental cycling test (during exercise)</td>
<td>La↓</td>
</tr>
<tr>
<td>Sear et al(^48)</td>
<td>8, M, 21 ± 1</td>
<td>Team amateur athletes (VO(_{2\text{max}}) 57.5 ± 3.7 mL ∙ kg(^{-1}) ∙ min(^{-1}))</td>
<td>WBC</td>
<td>45-min high-intensity interval treadmill running (during exercise)</td>
<td>TTE↑, VO(_{2\text{max}})↑↑, LA↑</td>
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</table>

(continued)
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample size, gender, age (y)</th>
<th>Athletic category</th>
<th>Characteristics of Compression Clothing</th>
<th>Applied pressure (mmHg)</th>
<th>Measure</th>
<th>Study protocol (occasion when compression clothing was applied)</th>
<th>Effects of compression clothing</th>
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<tbody>
<tr>
<td>Sperlich et al&lt;sup&gt;29&lt;/sup&gt;</td>
<td>15, M, 27 ± 5</td>
<td>Well-trained runners and triathletes (VO&lt;sub&gt;2max&lt;/sub&gt; 63.7 ± 4.9 mL · kg⁻¹ · min⁻¹)</td>
<td>Socks, tights, WBC</td>
<td>20</td>
<td>P</td>
<td>15-min treadmill running at 70% VO&lt;sub&gt;2max&lt;/sub&gt; followed by running to exhaustion at V&lt;sub&gt;max&lt;/sub&gt; of previous incremental test (during exercise)</td>
<td>VO&lt;sub&gt;2max&lt;/sub&gt;↑, TTE↓, VO&lt;sub&gt;2&lt;/sub&gt;↑↓, La↑↓, pO&lt;sub&gt;2&lt;/sub&gt;↑↓, SO&lt;sub&gt;2&lt;/sub&gt;↑↓, RPE↑</td>
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<tr>
<td>Davies et al&lt;sup&gt;33&lt;/sup&gt;</td>
<td>11, M+F, 20 ± 1</td>
<td>Netball and basketball, university level</td>
<td>Tights (G)</td>
<td>15</td>
<td>R</td>
<td>Intermittent jumping: 5 × 20 drop-jumps with 2-min rest between sets (compression 48 h after exercise)</td>
<td>Jump↑, sprint↑↓, swelling↑↑, DOMS↑↓, CK↑↓, damage marker↑↓</td>
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<tr>
<td>Higgins et al&lt;sup&gt;34&lt;/sup&gt;</td>
<td>9, F, 23 ± 5</td>
<td>Elite netball players</td>
<td>Tights</td>
<td>P</td>
<td>Intermittent sprinting and jumping in a simulated netball game (4 × 15 min; during exercise)</td>
<td>TTE↑</td>
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<tr>
<td>Houghton et al&lt;sup&gt;35&lt;/sup&gt;</td>
<td>12, M, 21 ± 2</td>
<td>Field hockey, amateur (VO&lt;sub&gt;2max&lt;/sub&gt; 58.6 ± 5.5 mL · kg⁻¹ · min⁻¹)</td>
<td>Shorts and shirt</td>
<td>P, R</td>
<td>Intermittent sprinting: 20-m sprints in a simulated hockey game (4 × 15 min; during exercise)</td>
<td>Sprint↑, RPE↑↓, HR↓,</td>
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<td>Kemmler et al&lt;sup&gt;36&lt;/sup&gt;</td>
<td>21, M, 39 ± 11</td>
<td>Moderately trained runners (VO&lt;sub&gt;2max&lt;/sub&gt; 52.0 ± 6.1 mL · kg⁻¹ · min⁻¹)</td>
<td>Socks (G)</td>
<td>24</td>
<td>P</td>
<td>Incremental treadmill running test (during exercise)</td>
<td>TTE↑, VO&lt;sub&gt;2max&lt;/sub&gt;↑, La↑</td>
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<tr>
<td>Silver et al&lt;sup&gt;6&lt;/sup&gt;</td>
<td>5, M, 24 ± 6</td>
<td>Highly strength-trained 1-RM bench press (&gt;125% BW)</td>
<td>Shirt</td>
<td>P</td>
<td>1-RM bench press, quantification of vertical and horizontal bar movements (during exercise)</td>
<td>Motor control↑</td>
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<tr>
<td>Duffield et al&lt;sup&gt;16&lt;/sup&gt;</td>
<td>14, M, 19 ± 1</td>
<td>Regional rugby players</td>
<td>Tights</td>
<td>P, R</td>
<td>Intermittent sprinting: 10- and 20-m sprints in a simulated rugby game (4 × 15 min), temp&lt;sub&gt;amb&lt;/sub&gt; 16–18°C (compression 18 h after exercise)</td>
<td>Sprint↑, strength &amp; power↑↓, CK↑↓, temp↑</td>
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<tr>
<td>French et al&lt;sup&gt;47&lt;/sup&gt;</td>
<td>10, M, 24 ± 3</td>
<td>Recreational/regional soccer and rugby players</td>
<td>Tights (G)</td>
<td>10–12</td>
<td>R</td>
<td>6 × 10 parallel squats at 100% BW + 11th repetition at 1-RM (compression 12 h after exercise)</td>
<td>CK↑↓, damage marker↑↓</td>
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<tr>
<td>Montgomery et al&lt;sup&gt;44&lt;/sup&gt;</td>
<td>10, M, 19 ± 2</td>
<td>Regional basketball players training 8–10 h/wk</td>
<td>Tights</td>
<td>18</td>
<td>R</td>
<td>3-day tournament with one 48-min game each day (compression 18 h after exercise)</td>
<td>Jump↑, sprint↓</td>
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<tr>
<td>Montgomery et al&lt;sup&gt;45&lt;/sup&gt;</td>
<td>10, M, 19 ± 2</td>
<td>Regional basketball players training 8–10 h/wk</td>
<td>Tights</td>
<td>18</td>
<td>R</td>
<td>3-day tournament with one 48-min game each day (compression 18 h after exercise)</td>
<td>Swelling↑, DOMS↑</td>
</tr>
<tr>
<td>Scanlan et al&lt;sup&gt;4&lt;/sup&gt;</td>
<td>12, M, 21 ± 4</td>
<td>Amateur cyclists (VO&lt;sub&gt;2max&lt;/sub&gt; 55.2 ± 6.8 mL · kg⁻¹ · min⁻¹)</td>
<td>Tights (G)</td>
<td>9–20</td>
<td>P</td>
<td>1-h time trial (on cycling ergometer; during exercise)</td>
<td>VO&lt;sub&gt;2max&lt;/sub&gt;↓, La↓↓</td>
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<tr>
<td>Study</td>
<td>Participants</td>
<td>VO$_{2\text{max}}$ (mL kg$^{-1}$ min$^{-1}$)</td>
<td>Exercise Protocol</td>
<td>Compressions Effects</td>
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<tr>
<td>Ali et al$^{12}$</td>
<td>14, M, 22 ± 1</td>
<td>Amateur runners: (1) 56.1 ± 0.4; (2) 55.0 ± 0.9</td>
<td>2 × 20-m shuttle-runs (separated by 1 h) and 10-km TT (road run; during exercise)</td>
<td>TT↓, RPE↔, DOMS↔, HR↔,</td>
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<tr>
<td>Duffield et al$^7$</td>
<td>10, M, 22 ± 1</td>
<td>Regional cricket players</td>
<td>Maximal-distance throwing, throwing accuracy, and intermittent sprinting; 20-m sprints/min for 30 min. Temp$_{\text{amb}}$ 15°C ± 3°C (during exercise, 24 h after)</td>
<td>La↑, SO$_2$↓, pO$_2$↓, sprint↑↓, strength &amp; power↑, RPE↓, HR↑, pH↓, CK↑↑, temp↑</td>
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<tr>
<td>Bringard et al$^6$</td>
<td>6, M, 31 ± 5</td>
<td>Well-trained runners (VO$_{2\text{max}}$ 60.9 ± 4.4)</td>
<td>Energy cost at 10, 12, 14, 16 km/h (temp$<em>{\text{amb}}$ 31°C) and 15-min treadmill running at 80% VO$</em>{2\text{max}}$. Temp$_{\text{amb}}$ 23.6°C (during exercise)</td>
<td>VO$_{2\text{max}}$↓, RPE↑, temp↑</td>
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<tr>
<td>Maton et al$^{15}$</td>
<td>15, M, 32 ± 6</td>
<td>Healthy (type of sport not specified)</td>
<td>Maintaining 50% of 1-RM ankle dorsiflexion to exhaustion (during exercise, 10 min after)</td>
<td>TTE↓, strength &amp; power↑</td>
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<tr>
<td>Trendell et al$^{8}$</td>
<td>11, M, 21 ± 3</td>
<td>Recreational athletes (type of sport not specified)</td>
<td>30-min downhill treadmill walking (6 km/h, 25% grade; compression 48 h after exercise)</td>
<td>DOMS↑, damage marker↑↓</td>
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<tr>
<td>Bernhardt et al$^{10}$</td>
<td>13, M+F, 26 ± 3</td>
<td>Healthy active students (type of sport not specified)</td>
<td>Active range of motion, agility test, balance test, joint-angle replication; 20-m sprint, vertical jump; 20-m shuttle run (during exercise)</td>
<td>VO$_{2\text{max}}$↔, jump↔↔, sprint↑↑, motor control↓</td>
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<tr>
<td>Kraemer et al$^{12}$</td>
<td>18, M+F, 21 ± 3</td>
<td>University volleyball players</td>
<td>10 consecutive countermovement jumps (during exercise)</td>
<td>Jump↑↓</td>
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<tr>
<td>Berry et al$^{15}$</td>
<td>6, M, 23 ± 5</td>
<td>Well-trained: (1) 52.8 ± 8.0; (2) 59.9 ± 6.8</td>
<td>Incremental treadmill running test to determine VO$<em>{2\text{max}}$ and 3 min at 110% VO$</em>{2\text{max}}$ (on cycling ergometer; during exercise)</td>
<td>VO$_{2\text{max}}$↑, TT↔</td>
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</table>

**Abbreviations:** M, male; F, female; VO$_2$, oxygen uptake; G, graduated; P, performance; R, recovery; TT, time trial; ↔, no effect from compression; ↓, negative effect from compression; CP, cardiac parameters (HR, cardiac output, cardiac index, stroke volume); ↑↓, contradictory results: positive, as well as negative, effects from compression; RPE, rating of perceived exertion; temp$_{\text{amb}}$, ambient temperature; ↑, a positive effect from compression; TTE, time to exhaustion; SO$_2$, oxygen saturation; HR, heart rate; jump, vertical-jump exercise; Sprint, short-duration sprinting; DOMS, delayed onset of muscle soreness; CK, creatine kinase; damage marker, additional muscle damage marker; WBC, whole-body compression; 1-RM, 1-repetition maximum; pO$_2$, oxygen partial pressure; Swelling, muscle swelling; strength & power, strength and power exercise; temp, body temperature; BW, body weight.
Figure 2 — Effect sizes of the application of compression clothing on performance enhancement.
Figure 3 — Effect sizes of the application of compression clothing on recovery enhancement.
Figure 4 — Different types of compression applied in the 31 studies: a) shirt (n = 2), tights (n = 14), and whole-body compression (n = 4); b) shorts (n = 3) and knee-high socks (n = 9); and c) stockings (n = 2).

Recovery

The current analysis revealed small positive effects on recovery of strength and power tasks (ES = 0.10) such as peak leg power on a cart dynamometer, maximal-distance throwing, and isolated plantar flexion. When applying compression compared with noncompression clothing, recovery of vertical-jump performance was also positively affected (ES = 0.13, Figure 3). However, the recovery of short-sprint ability (10–60 m) was negatively affected by the use of compression clothing (ES = –0.13).

The application of compression clothing had no effect on heart-rate recovery (ES = 0.07, Figure 3). On the other hand, our analysis discovered small effects on postexercise lactate removal (ES = 0.20) although there was no effect on plasma pH (ES = 0.02).

Recovery-related parameters showed a moderate effect on the reduction of muscle swelling (ES = 0.35, Figure 3) and delayed onset of muscle soreness (ES = 0.47) when compression clothing was worn for 12 to 48 hours after exercise. Small negative effects regarding muscle-damage markers were detected for levels of creatine kinase (ES = –0.10) and no effects for other myocellular proteins were found (ES = –0.01).

Body temperature was highly affected by the use of compression clothing, with large increases (ES = 1.38) during and after intermittent high-intensity exercise (15–18°C) and submaximal running (23–31°C).

Discussion

The ES calculations indicated small ESs for the application of compression clothing during exercise for improving short-duration sprints (10–60 m), vertical-jump height, and time to exhaustion (such as running at VO2max or during incremental tests), as well as time-trial performance (3–60 min). When compression clothing was applied for recovery purposes 12 to 48 hours after exercise, small or moderate effects were also observed for recovery of maximal strength and power performance, recovery of vertical-jump performance, blood lactate removal, reductions in muscle swelling and perceived muscle pain, and increased body temperature.

It is worth mentioning that compression clothing is also used by individuals who run but suffer from medial tibial stress syndrome, for example (a common running injury), or by individuals who suffer from chronic venous insufficiency. Therefore, the current results based on healthy individuals may not be the same in injured and unhealthy individuals who practice sports.

Endurance Exercise

While previous research concluded that there is some evidence that submaximal oxygen use is altered by the application of compression clothing, our ES calculation cannot confirm those findings in general. Based on the average ES calculations, none of the physiological markers during exercise, such as oxygen uptake, blood lactate concentration during continuous exercise, blood gases, or cardiac parameters, were affected (Figure 2).

However, 7 studies that evaluated time to exhaustion and 3 examining time-trial performance demonstrated positive effects attributed to the application of compression clothing. It has been shown that time-to-exhaustion tests are less reliable (coefficient of variation >10%) than constant-duration tests (coefficient of variation <5%), which may explain why these findings are not in line with the possible underlying physiological markers. Since it is difficult to create a placebo condition for compression clothing, it cannot be excluded that extended time to exhaustion is due to improved perceptions and a result of the participants’ intuitions of expected findings. But the overall sensation of vitality plays a crucial role in exercise performance, and any changes in perceived exertion during exercise may serve as an ergogenic aid for improving performance regardless of potential physiological effects.

Earlier research has recommended applying graduated compression clothing, with pressure decreasing continuously from distal to proximal to improve hemody-
namics. Due to the various differences in leg dimensions among a given population, it was recommended that compression clothing be custom made and individually fitted to have a proper amount of pressure on the various parts of the limbs. None of the reviewed studies indicated the use of custom-made compression clothing, and 17 of 31 studies applied graduated compression. Therefore, the lack of effects on physiological parameters such as oxygen uptake or cardiac parameters might partly be due to insufficient or inappropriate compression properties of the applied compression clothing.

**Strength and Power Exercise**

While MacRae et al. reported mixed results for jumping performance and that sprinting was unaffected by the application of compression clothing, our ES calculation revealed small positive effects on single and repeated sprint performance and vertical jumping. Repeated-sprint ability, and short-duration sprints separated by short recovery periods, was shown to rely on metabolic and neuronal factors such as H+ buffering, oxidative capacity, muscle activation, and muscle-fiber-recruitment strategies. Since our ES calculation indicated positive effects on lactate removal after and between bouts of high-intensity exercise, the application of compression clothing seems to aid performance and recovery. It is suggested that hemodynamic and neuronal mechanisms such as improved venous return, enhanced arterial inflow, altered muscle-fiber-recruitment patterns, and altered proprioception account for these performance improvements (Figure 5).

**Venous Return.** The blood is driven through the vascular system by the propulsive force of each heartbeat, with the blood pressure being almost zero when the blood enters the venous system. In addition, gravity creates a hydrostatic force of 80 to 100 mmHg in an upright body position that counteracts venous return. Since unidirectional valves are located in the veins, the blood is directed toward the heart with each muscle contraction of the peripheral limbs due to compression on the veins. In shifting superficially located blood to the deeper venous system, the application of compression clothing supports the valve system and aids venous hemodynamics.

Improved venous hemodynamics have been suggested to result in increased end-diastolic filling of the heart, increasing stroke volume and cardiac output. Since stroke volume is a limiting factor for performance, the application of compression clothing could serve as an ergogenic aid. In this context, Sperlich et al. applied 0, 10, 20, 30, and 40 mmHg of sock compression to the calf muscles of runners and reported no changes in cardiac output, cardiac index, or stroke volume. From these knee-high-sock compression data, it remains questionable whether the improved venous hemodynamics (stimulated by a fairly low area of compressed calf muscles) will affect central circulatory and cardiac parameters such as stroke volume and heart rate. However, the application of compression clothing may enhance removal of metabolites and supply of nutrients, which is in line with the findings of the ES calculation showing improved lactate removal (Figure 3).

**Arterial Inflow.** Similar to the improvements in venous hemodynamics, the application of compression clothing was shown to improve arterial inflow to forearm muscles. This improvement was associated with enhanced local blood flow and improved oxygen delivery and muscle oxygenation. In general, the diameter of the arteries and arterioles is influenced by changes in the transmural pressure gradient. The so-called myogenic response provides a constant blood flow in the precapillary vessels with each heartbeat pumping blood into the circulation. As the pressure of the compression clothing is transmitted into the deeper underlying tissue, the vessels’ transmural pressure gradient decreases. The myogenic response of the arteries and arterioles leads to vasodilatation and favors arterial inflow to the muscle, hence increasing local blood inflow.

In supporting venous and arterial blood flow, the wearing of compression clothing was associated with increased clearance of metabolites and supply of nutrients. Since repeated-sprint ability relies on metabolic factors such as H+ buffering and oxidative capacity, the application of compression clothing could serve as an ergogenic aid. The ES calculation supports this in showing positive effects of the use of compression clothing on lactate removal during high-intensity exercise. Therefore, compression clothing may improve performance, especially during high-intensity exercise, by supporting hemodynamics.

**Neural Mechanisms.** Power production, especially short-duration sprints, relies on neural factors such as muscle activation and recruitment strategies. Compression clothing has been linked to improved proprioception, which is the awareness of the body segments and position in space, allowing the individual to know the direction, acceleration, and speed of the limbs during movement. Sensory feedback is provided by mechanoreceptors located in the skin, muscles, ligaments, joint capsules, and connective tissue. It has been shown that the activation of these receptors reduces presynaptic inhibition, thus increasing sensory feedback. The use of compression clothing most likely activates the mechanoreceptors in the superficial tissues, enhances sensory feedback, and improves proprioception. Since neural factors such as muscle activation and muscle-fiber-recruitment strategies influence power production, improved proprioception from the application of compression clothing corresponds with the ES calculation showing positive effects on short-sprint ability and vertical-jump exercise.

**Mechanical Properties.** It has been shown that compression clothing decreases oscillatory displacement of the leg muscles during vertical jumping and reduces the number of recruited muscle fibers as detected by a decrease in myoelectric activity. Therefore, decreased energy expenditure during submaximal running, delayed
Figure 5 — Biological and psychological mechanisms underlying the application of compression clothing.
fatigue during repetitive vertical-jump exercise, and reduced structural damage during intermittent sprinting, which were related to decreased oscillatory displacement of the leg muscles by the application of compression clothing. In this case, a fairly high amount of pressure seems to be necessary to reduce the oscillatory displacement. Since only 20 of 31 of the reviewed studies indicated the amount of applied pressure, it is difficult to conclude the optimal amount of pressure for certain exercise modes. Future research is needed to clarify the optimal amount of pressure exerted by compression clothing to reduce oscillatory displacement without negatively affecting hemodynamics.

Recovery 24 to 48 Hours After Exercise

The ES calculation confirms the findings of earlier research, concluding an improved recovery of various power and torque measurements with the application of compression clothing 24 to 48 hours after fatiguing exercise. Although jumping exercise was not affected in a previous analysis, our ES calculation showed an improved recovery of vertical jumping (ES = 0.10). These findings may be explained by other physiological markers such as reductions in muscle swelling (ES = 0.35), delayed onset of muscle soreness (ES = 0.47), and increased body temperature (ES = 1.38). Most studies that investigated the effect of compression on recovery applied compression clothing during and/or after exercise. Applying compression exclusively during continuous exercise did not show any benefits for recovery 24 hours after exercise. Therefore, it seems essential to wear compression clothing for at least 12 to 24 hours after exercise to improve recovery.

MacRae et al. concluded that compression garments produced mixed results for markers of muscle damage and inflammation, as well as immediate and delayed onset of muscle soreness. The current ES calculation revealed negative effects on levels of creatine kinase (ES = -0.10) but no effect on other myofibrillar proteins through the application of compression clothing (ES = -0.01). However, the reduction in muscle soreness 24 to 48 hours after exercise showed medium positive effects (ES = 0.47) with the use of compression clothing. The application of compression clothing was suggested to improve recovery after muscle-damaging exercise protocols by enhancing lymphatic outflow, thus reducing postexercise muscle swelling and pain (Figure 5). Furthermore, increased arterial inflow and venous return were associated with increased clearance of cellular waste products, potentially enhancing cellular repair processes.

Lymphatic Outflow. Especially after high-intensity exercise, muscle pain and swelling can occur due to structural damage to the contractile elements of the muscles. The following necrosis of the damaged muscle cells and the infiltration of neutrophil cells (immune cells) result in an inflammatory response. Furthermore, the proteins of the damaged contractile elements are released into the interstitial fluid, contributing to elevated tissue osmotic pressure. To equalize the osmotic gradient, fluid from the circulatory system is absorbed, which increases the interstitial fluid and intracompartmental pressure, resulting in edema.

Applying compression clothing may reduce exercise-induced edema by promoting lymphatic outflow and transporting the profuse fluid from the interstitium of the muscle back into the circulation. Thereby, intracompartmental pressure is reduced, decreasing pain and serving as a nonpharmaceutical treatment of edema after high-intensity exercise in trained athletes.

It remains unclear why the removal of muscle-damage markers such as creatine kinase was negatively affected, whereas other muscle-damage markers such as lactate dehydrogenase were unaffected. Nevertheless, these enzymes serve as global markers for damage to contractile elements and act as indicators of recovery rather than providing evidence for its progress.

Thermoregulation. The application of compression clothing showed a large positive effect on body temperature (ES = 1.38). In general, clothing by itself imposes a physical barrier to heat transfer and hinders sweat evaporation from the skin by representing a layer of insulation.

In this context, an interaction between muscle blood flow and skin and muscle temperature has been reported, and compression clothing has been shown to diminish skin perfusion. This imposition results in a reduction of the thermoregulatory effects of sweat evaporation in addition to the insulating properties of the garment. While the elevated muscle temperature induced by compression clothing might be positive for recovery purposes, the rise in muscle temperature beyond optimal may inhibit performance during endurance exercise in hot environments. However, 2 of 3 included studies on compression clothing assessed in this review were performed in moderate environmental conditions (15–18°C). Under these conditions, the reduction in evaporation is suggested to be less important while there is an increased reliance on conduction, as well as convection, which does not result in impaired performance. So far, no study has investigated the effect of compression clothing in winter sports. Since the reduction in skin blood flow would increase blood volume in the working muscles, compression might especially serve as an ergogenic aid in performance in cold environmental conditions. Therefore, compression clothing can be applied with cognizance of the underlying atmospheric conditions and duration of the exercise.

Practical Application and Conclusion

Based on our ES calculations summarizing the findings of 31 studies independent of statistical significance, compression clothing promotes numerous physiological processes capable of assisting athletic performance and subsequent recovery. However, in some cases there is
little evidence to support some of the purported benefits, and gaps in knowledge are still evident. The magnitude of the effects should also be taken into account when assessing the meaningfulness and practical relevance of the use of compression clothing in a given situation. Based on our ES calculation, we conclude that there are beneficial effects of compression clothing, especially during intermittent high-intensity exercise such as repeated sprinting and jumping, rather than during submaximal endurance exercise. Furthermore, the benefits of compression clothing seem to be most pronounced when it is applied for recovery purposes 12 to 48 hours after significant amounts of muscle-damage-inducing exercise.

Most of the reviewed studies applied lower body compression (ie, knee-high socks, shorts, or tights) with and without distal-to-proximal pressure gradient for performance enhancement. Based on our findings, we conclude that the application of compression clothing during exercise has small effects on improving short-duration sprints (10–60 m), vertical-jump height, and time to exhaustion (such as running at VO2max, or during incremental tests), as well as time-trial performance (3–60 min). The use of upper body compression may be of practical relevance to support upper body exercise; however, further research is warranted on this topic. Since several sports regulate their athletes’ competition outfit, we recommend the application of lower and upper body compression according to the regulations, nature of sport, and environmental conditions.

If compression clothing is worn for recovery purposes 12 to 48 hours after exercise, we conclude small or moderate effects for recovery after maximal strength and power, particularly vertical-jump exercise; reductions in muscle swelling and perceived muscle pain; and blood lactate removal. Large effects are evident for increased body temperature.

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