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Authors: Dennis-Peter Born[1], Billy Sperlich[1], Hans-Christer Holmberg[2]

Affiliations: [1]University of Wuppertal, Department of Sport Science, Wuppertal, Germany. [2]Swedish Winter Sports Research Centre, Department of Health Sciences, Mid Sweden University, Östersund, Sweden.

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Bringing light into the dark: Effects of compression clothing on performance and recovery

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Authors: *Dennis-Peter Born*[1*], *Billy Sperlich*[1], *Hans-Christer Holmberg*[2]

1University of Wuppertal, Department of Sport Science, Fuhlrottstraße 10, 42119 Wuppertal, Germany

2Swedish Winter Sports Research Centre, Department of Health Sciences, Mid Sweden University, 83125 Östersund, Sweden

* Corresponding author:
Dennis-Peter Born
University of Wuppertal
Department of Sport Science
Fuhlrottstraße 10
42119 Wuppertal
Germany
Tel.: +49/202/439-2962
Fax.: +49/202/439-3745
E-mail: dennis.born@web.de

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Abstract

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 during 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, physiological, psychological and biomechanical parameters during and/or post exercise were included and means and measures of variability of the outcome measures recorded for the estimation of the effect size (Hedges'g) and associated 95% confidence intervals for comparisons of an experimental (compression) and a control trial (non-compression). 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: 1) short-duration sprints (10 to 60-m), 2) vertical jumping height, 3) extending the time to exhaustion (such as running at VO_{2max} or during incremental tests) and 4) time trial performance (3 to 60-min). When compression clothing was applied for recovery purposes *after* exercise, small to moderate effect sizes were observed in: 1) recovery of maximal strength and power, especially vertical jumping exercise; 2) reductions in muscle swelling and perceived muscle pain; 3) blood lactate removal; and 4) 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.

***Key Words*:** blood flow; cardiac output; heart rate; muscle damage; oxygen uptake; oscillation; venous hemodynamics

Introduction

In the past two 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 or full-length tights are the most common types of compression garments. In order 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 among 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] 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, one review summarizes the findings of the application of compression clothing for exercise and recovery and base their conclusions mostly on the statistically significant results in the reviewed articles.[18] This review also concludes some isolated indications for physical and physiological effects, including attenuation of muscle oscillation, improved joint awareness, perfusion augmentation and altered oxygen usage at sub-maximal 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 condition 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 control trial.[19] Therefore, it seems more relevant to calculate effect sizes in order 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 should be 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 the calculation of the effect size 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 the 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 in order 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 1) summarize results from existing data, 2) to identify the benefits for endurance, strength as well as power and motor control, 3) quantify effects on physiological, psychological and biomechanical parameters, 4) identify possible underlying mechanisms for observed results and 5) provide recommendations for the athlete and/or consumer.

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 for the retrieval of 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 endurance as well as power (n = 5) during and/or after exercise. The studies had to assess physiological, biomechanical and/or psychological parameters during and/or after exercise. Only studies that presented absolute data as means and measures of variability for the calculation of effect sizes from an experimental ("compression") and a control group ("non-compression") were included. Finally, the research must have been conducted on participants without any cardio-vascular, metabolic or musculoskeletal disorders (Figure 1).

Quality Assessment

Each study meeting the inclusion criteria was additionally evaluated with the Physiotherapy Evidence Database (PEDro) scale by two independent reviewers.[24] On the PEDro scale an item answered with "yes" adds 1 point to the score and "no" contributing 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, effect sizes for each study were determined as proposed by Glass.[28] For each parameter, the effect size (Hedges' g) and associated 95% confidence interval were calculated. Hedges' g was computed using the difference between means of an experimental ("compression") and control ("non-compression") group divided by the average population standard deviation.[20] To optimize the effect size 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 effect sizes (ES) were then defined as trivial (<0.10), small (0.10-0.30), moderate (0.30-0.50), or large (> 0.50).[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 indicating 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 study protocols for each study are summarized in Table 1. The calculated ES 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 to 21), age (19 to 39 yrs), gender of the participants (male n = 22, female n = 3, mixed gender n = 5, no gender information n = 1) and the 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) which 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)[29,31-36] and time trial performance (3 to 60-min)[12,15,37] indicated small positive effects (ES = 0.15). Additionally, endurance-related parameters, such as sub-maximal 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 saturation[2,7,29] and partial pressure of oxygen (ES = 0.01),[7,29] as well as cardiac parameters including heart rate,[2,32,37,38,40] cardiac output, cardiac index and stroke volume[2] (ES = -0.08) were not affected by the application of compression compared to non-compression clothing.

Small positive ES (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] while wearing compression clothing. Peak leg power measured on a cart dynamometer[16] and performance during maximal distance throwing[7] were not affected when wearing compression clothing (ES = 0.00). In addition, there were no effects on balance, joint position sensing[30] and arm tremble during bench press[6] (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.

Recovery

The present analysis revealed small positive effects on recovery of strength and power tasks (ES = 0.10) such as peak leg power on a cart dynamometer,[16] maximal distance throwing,[7] and isolated plantar flexion.[35] When applying compression compared to non-compression clothing, recovery of vertical jumping performance was also positively affected (ES = 0.13, Figure 3).[37-39,43,44] However, the recovery of short sprinting ability (10-60-m) was negatively affected by the use of compression clothing (ES = -0.13).[7,16,30,39,43,44]

The application of compression clothing had no effect on heart rate recovery (ES = 0.07, Figure 3).[7,12,39,41] On the other hand, our analysis discovered small effects on post-exercise lactate removal (ES = 0.20)[7,39,40], although there was no effect on plasma pH (ES = 0.02).[7,39]

Recovery related parameters reported a moderate effect on the reduction of muscle swelling (ES = 0.35, Figure 3)[43-45] and delayed onset of muscle soreness (ES = 0.47)[12,16,39,43-46] when compression clothing was worn for 12 to 48h after exercise. Small negative effects regarding muscle damage markers were detected for levels of creatine kinase (ES = -0.10)[7,11,16,39,43,47,48] and no effects for other myocellular proteins were found (ES = -0.01).[39,43,46,47]

Body temperature was highly affected by the use of compression clothing with large increases (ES = 1.38, Figure 3) during and post intermittent high intensity exercise (15-18°C)[7,16] and sub-maximal running (23-31°C).[1]

Discussion

The effect size calculations indicated small ES for the application of compression clothing *during* exercise for improving: 1) short-duration sprints (10 to 60-m), 2) vertical jumping height and 3) the time to exhaustion (such as running at VO_{2max} or during incremental tests) as well as time trial performance (3 to 60-min). When compression clothing was applied for *recovery* purposes 12 to 48h after exercise, small or moderate effects were also observed for: 1) recovery of maximal strength and power performance, 2) recovery of vertical jumping performance; 3) blood lactate removal; 4) reductions in muscle swelling and perceived muscle pain; and 5) increased body temperature.

It is worth mentioning that compression clothing is also used by individuals who run, but who suffer from medial tibial stress syndrome, for example (a common running injury), or by individuals who suffer from chronic venous insufficiency. Therefore, the present results that are 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 sub-maximal oxygen usage is altered by the application of compression clothing[18] our effect size calculation cannot confirm these findings in general. Based on the average effect size calculations, none of the physiological markers during exercise such as oxygen uptake, blood lactate concentration during continuous exercise, blood gases nor cardiac parameters where affected (Figure 2).

However, seven studies that evaluated time to exhaustion and three 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, such as time trials (coefficient of variation <5%)[49] and may therefore 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 the effects of an extended time to exhaustion is due to improved perceptions and a result of the participants' intuitions of expected findings.[12] But the overall sensation of vitality plays a crucial role in exercise performance,[50] and any changes in the perceived exertion during exercise may serve as an ergogenic aid for improving performance regardless of potential physiological effects.[7]

Earlier research has recommended to apply graduated compression clothing with pressure decreasing continuously from distal to proximal in order to improve hemodynamics.[5] Due to the various differences in leg dimensions among a given population it was recommended that compression clothing should be custom made and individually fitted in order to have a proper amount of pressure on the various parts of the limbs.[43] None of the reviewed studies indicated the use of custom made compression clothing and 17 of 32 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 and co-workers[18] reported mixed results for jumping performance and that sprinting is 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.[51] 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 hemodynamical and neuronal mechanisms such as improved venous return,[5,13,52] enhanced arterial inflow,[53] altered muscle fiber recruitment pattern[1,50] and proprioception[54,55] account for these performance improvements (Figure 5).

Venous Return

The blood is driven through the vascular system by the propulsive force of each heart beat with the blood pressure being almost zero when the blood enters the venous system. Additionally, gravity creates a hydrostatic force of 80 to 100 mmHg in an upright body position which counteracts the venous return.[56] Since unidirectional valves are located in the veins, the blood is directed towards 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[5] the application of compression clothing supports the valve system and aids venous hemodynamics.[5,13,52]

Improved venous hemodynamics have been suggested to result in an increased end-diastolic filling of the heart, increasing stroke volume and cardiac output.[12] Since the stroke volume is as a limiting factor for performance,[57] the application of compression clothing could serve as an ergogenic aid. In this context, Sperlich and co-workers[2] 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 this 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[58] 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.[53] This improvement was associated with an enhanced local blood flow, improved oxygen delivery and muscle oxygenation.[14] In general, the diameter of the arteries and arterioles is influenced by changes in the transmural pressure gradient.[59] The so-called myogenic response provides a constant blood flow within the precapillary vessels with each heart beat pumping the blood into the circulation. As the pressure of the compression clothing is transmitted into the deeper underlying tissue[60] the vessels' transmural pressure gradient decreases.[61] The myogenic response of the arteries and arterioles leads to vasodilatation and favors the arterial inflow to the muscle, hence increasing local blood inflow.[53]

In supporting venous[5,13,52] and arterial blood flow[53] the application of compression clothing was associated with increased clearance of metabolites and supply of nutrients.[58] Since repeated-sprint ability relies on metabolic factors such as H^+ buffering and oxidative capacity, the application of compression clothing could serve as ergogenic aid.[51] The ES calculation supports this in showing positive effects by the application 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.[51] Compression clothing has been linked to improve 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.[62] Sensory feedback is provided by mechanoreceptors located in the skin, muscles, ligaments, joint capsules and connective tissue.[62] It has been shown, that the activation of these receptors reduces pre-synaptic inhibition[63,64] thus increasing the sensory feedback.[30] The application of compression clothing most likely activates the mechanoreceptors in the superficial tissues, enhances sensory feedback[65] and improves proprioception.[54,55] Since neural factors such as muscle activation and muscle fiber recruitment strategies influence power production,[51] improved proprioception by the application of compression clothing corresponds with the ES calculation showing positive effects on short-sprint ability and vertical jumping exercise.

Mechanical Properties

It has been shown that compression clothing decreases the oscillatory displacement of leg muscles during vertical jumping[8,50] and reduces the number of recruited muscle fibers as detected by a decrease in myoelectric activity.[66] Therefore, decreased energy expenditure during sub-maximal running,[1] delayed fatigue during repetitive vertical jumping exercise[50] and reduced structural damage during intermittent sprinting[39] was related to a decreased oscillatory displacement of leg muscles by the application of compression clothing. In this case, a fairly high amount of pressure seems to be necessary in order to reduce the oscillatory displacement. Since 20 of 32 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 impacting hemodynamics.

Recovery 24 to 48-h after exercise

The ES calculation confirms the findings of earlier research[18] concluding an improved recovery of various power and torque measurements with the application of compression clothing 24 to 48-h after fatiguing exercise. Although jumping exercise were not affected in a previous analysis[18], 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-h after exercise.[38] Therefore, it seems to be essential to wear compression clothing for at least 12 to 24-h after exercise in order to improve recovery.

MacRae and co-workers[18] 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 present 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-h after exercise showed medium positive effects (ES = 0.47) when wearing compression clothing. The application of compression clothing was suggested to improve recovery after muscle damaging exercise protocols by enhancing lymphatic outflow, thus reducing post-exercise muscle swelling and pain[67] (Figure 5). Furthermore, an increased arterial inflow[14,53] and venous return[5,13,52] were associated with an increased clearance of cellular waste products, potentially enhancing cellular repair processes.[43,46]

Lymphatic Outflow

Especially after high-intensity exercise, muscle pain and swelling can occur due to structural damage to the contractile elements of the muscles.[68,69] The following necrosis of the damaged muscle cells and the infiltration of neutrophil cells (immune cells) results in an inflammatory response.[68] Furthermore, the proteins of the damaged contractile elements are released into the interstitial fluid contributing to an elevated tissue osmotic pressure.[67] To equalize the osmotic gradient, fluid from the circulatory system is absorbed, which increases the interstitial fluid and intra-compartmental pressure, resulting in edema.[67]

Applying compression clothing may reduce exercise-induced edema by promoting the lymphatic outflow and transporting the profuse fluid from the interstitium of the muscle back into the circulation.[67,70] Thereby the intra-compartmental pressure is reduced, decreasing pain[67] and serving as non-pharmaceutical treatment of edema following high-intensity exercise in trained athletes.[10]

It remains unclear why the removal of muscle damage markers such as creatine kinase was negatively affected whereas additional 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.[71,72]

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.[73]

In this context, an interaction between muscular blood flow and skin and muscle temperature has been reported[74] and compression clothing shown to diminish the skin perfusion.[17] 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.[7,8] However, two of three included studies on compression clothing assessed in this review were performed at moderate environmental conditions (15-18°C).[33,36] Under these conditions, the reduction in evaporation is suggested to be less important where there is an increased reliance on conduction as well as convection which does not result in impairments of performance.[39] So far, no study 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 serve as ergogenic aid in performance especially in cold environmental conditions. Therefore, compression clothing can be applied with cognizant 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 effect size 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 sub-maximal endurance exercise. Furthermore, the benefits of compression clothing seem to be most pronounced when applied for recovery purposes 12 to 48-h after significant amounts of muscle-damage-inducing exercise.

The majority of the reviewed studies have applied lower body compression (i.e. 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: 1) short-duration sprints (10 to 60-m), 2) vertical jumping height and 3) time to exhaustion (such as running at VO_{2max} or during incremental tests) and time trial performance (3 to 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 the athlete's competition outfit we recommend the application of lower and upper body compression according to the regulations, nature of sport and environmental conditions.

If the compression clothing is worn for recovery purposes 12 to 48-h *after* exercise, we conclude small or moderate effects for: 1) recovery after maximal strength and power, particularly vertical jumping exercise; 2) reductions in muscle swelling and perceived muscle pain; and 3) blood lactate removal. Large effects are evident for increased body temperature.

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"Brief Review: Bringing Light into the Dark: Effects of Compression Clothing on Performance and Recovery"
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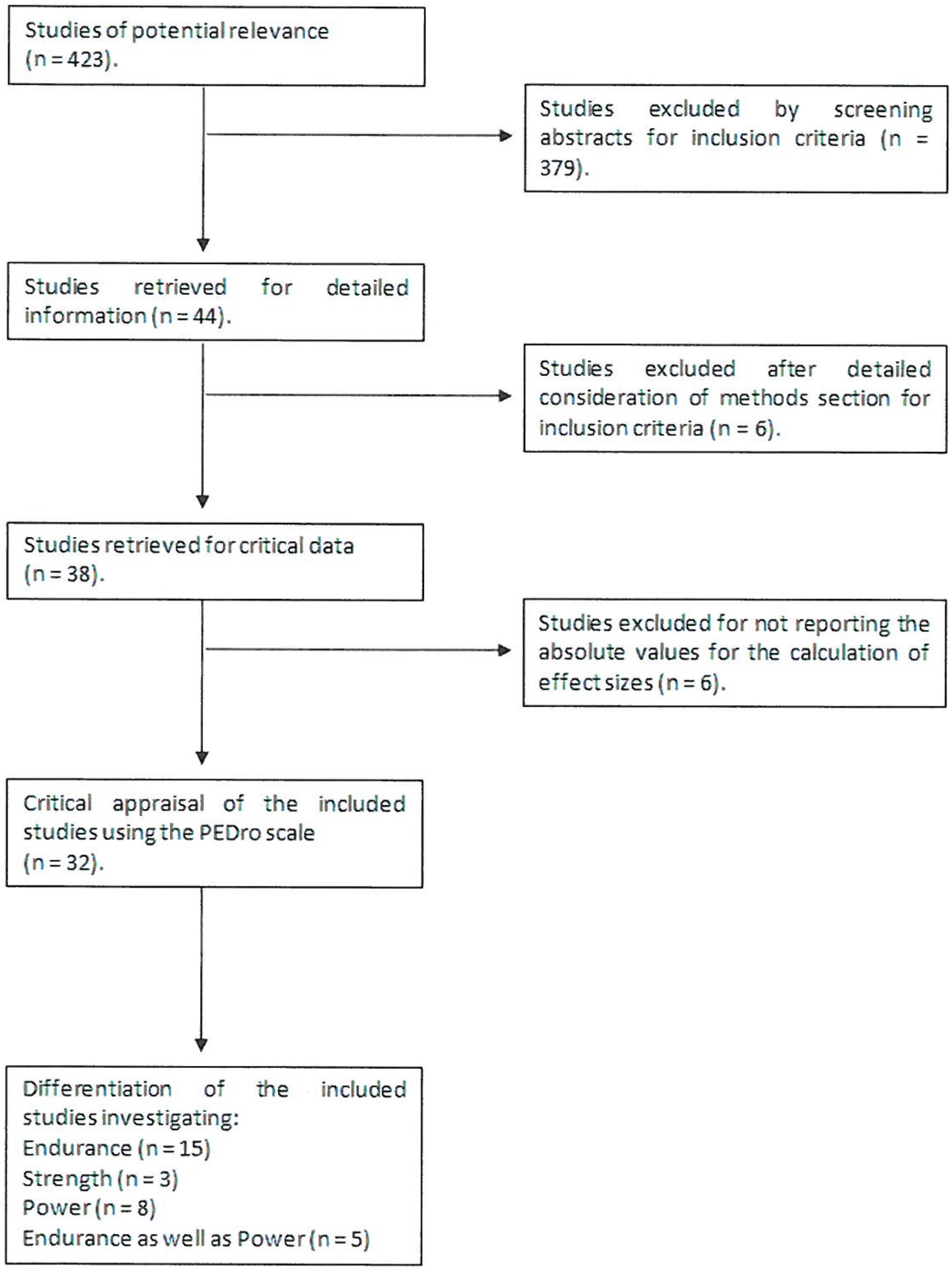

Figure 1 - Process of study selection for the inclusion of the systematic review.

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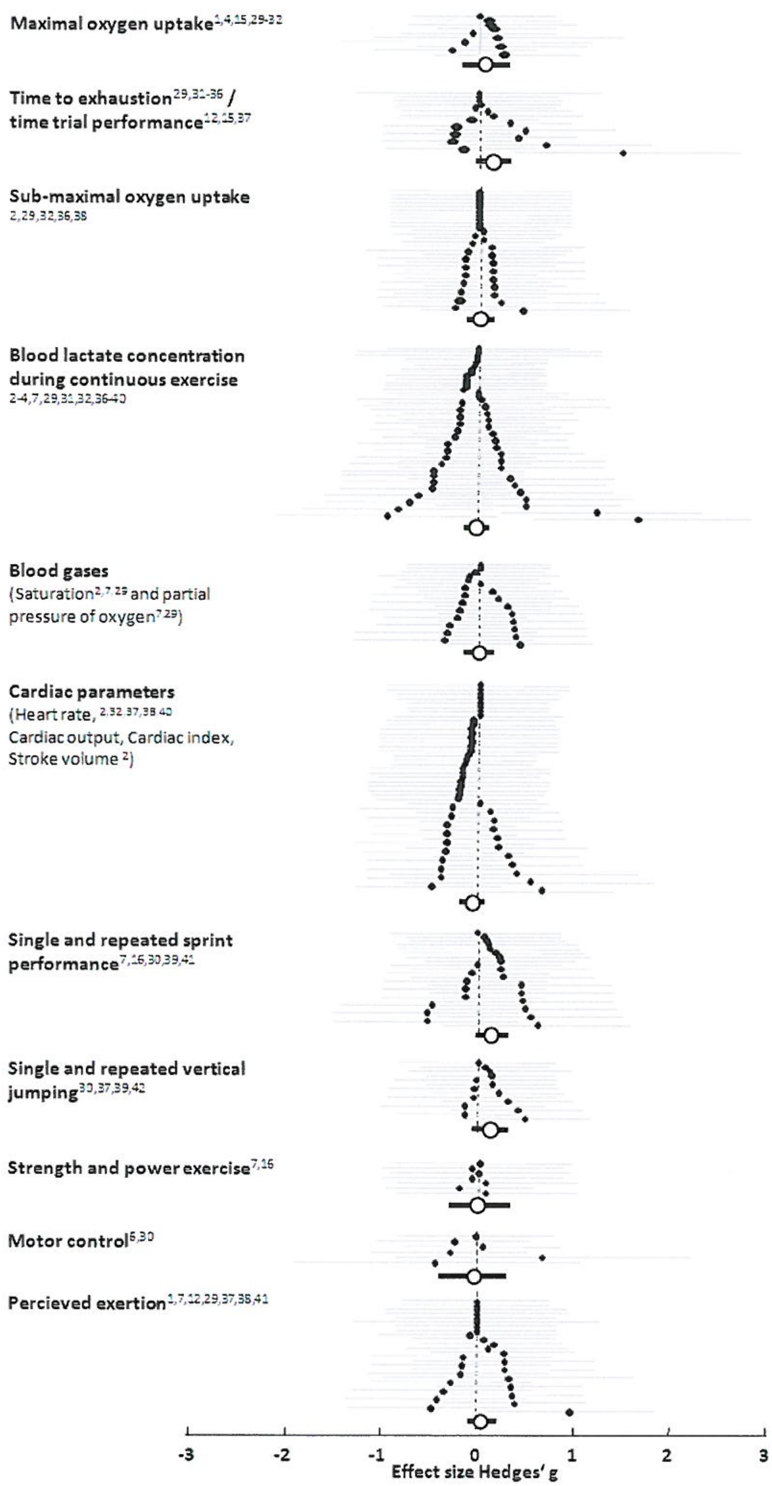

Figure 2 - Effect sizes of the application of compression clothing on performance enhancement.

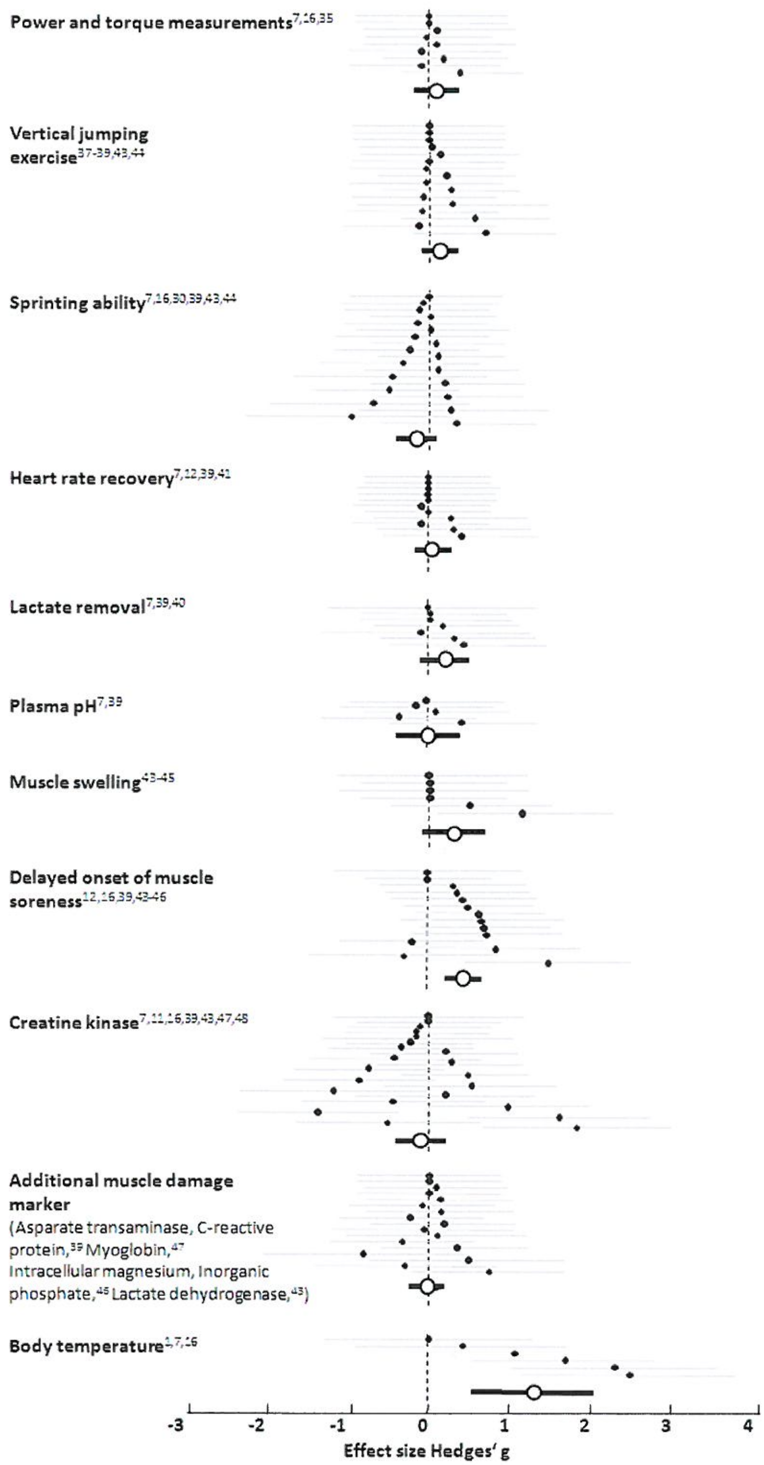

Figure 3 - Effect sizes of the application of compression clothing on recovery enhancements.

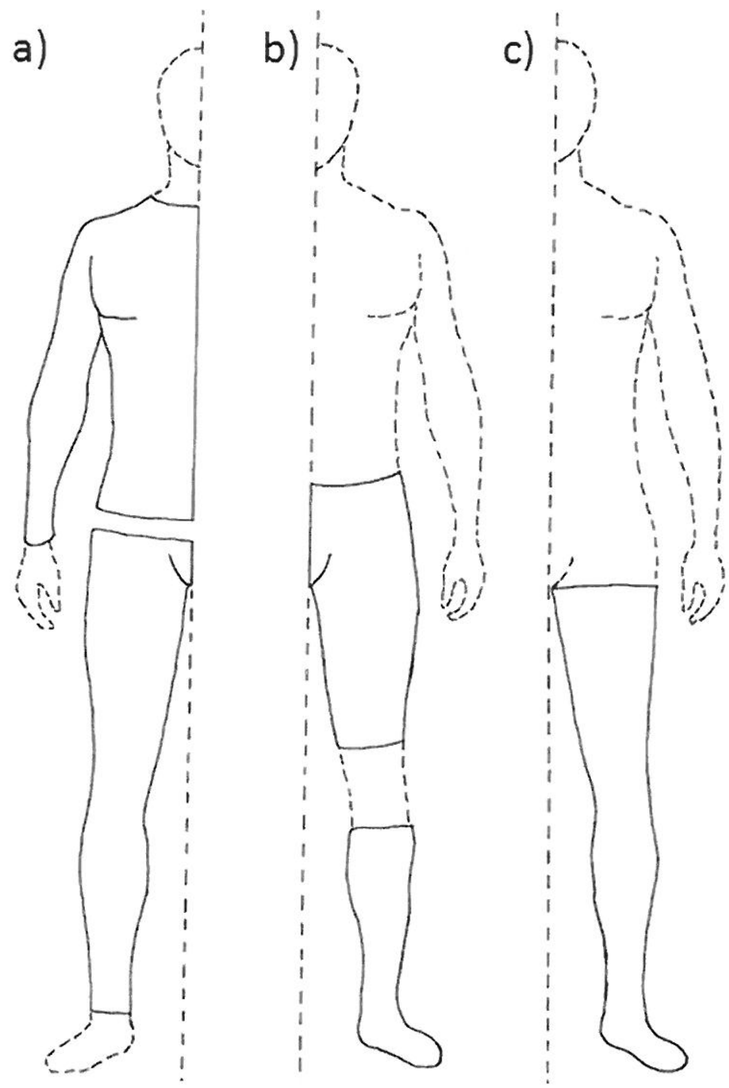

Figure 4 - Different types of compression applied in the 31 studies: a) Shirt (n = 2), Tights (n = 14) and Whole body compression (n = 4), b) Shorts (n = 3) and Knee-high Socks (n = 9), c) Stockings (n = 2).

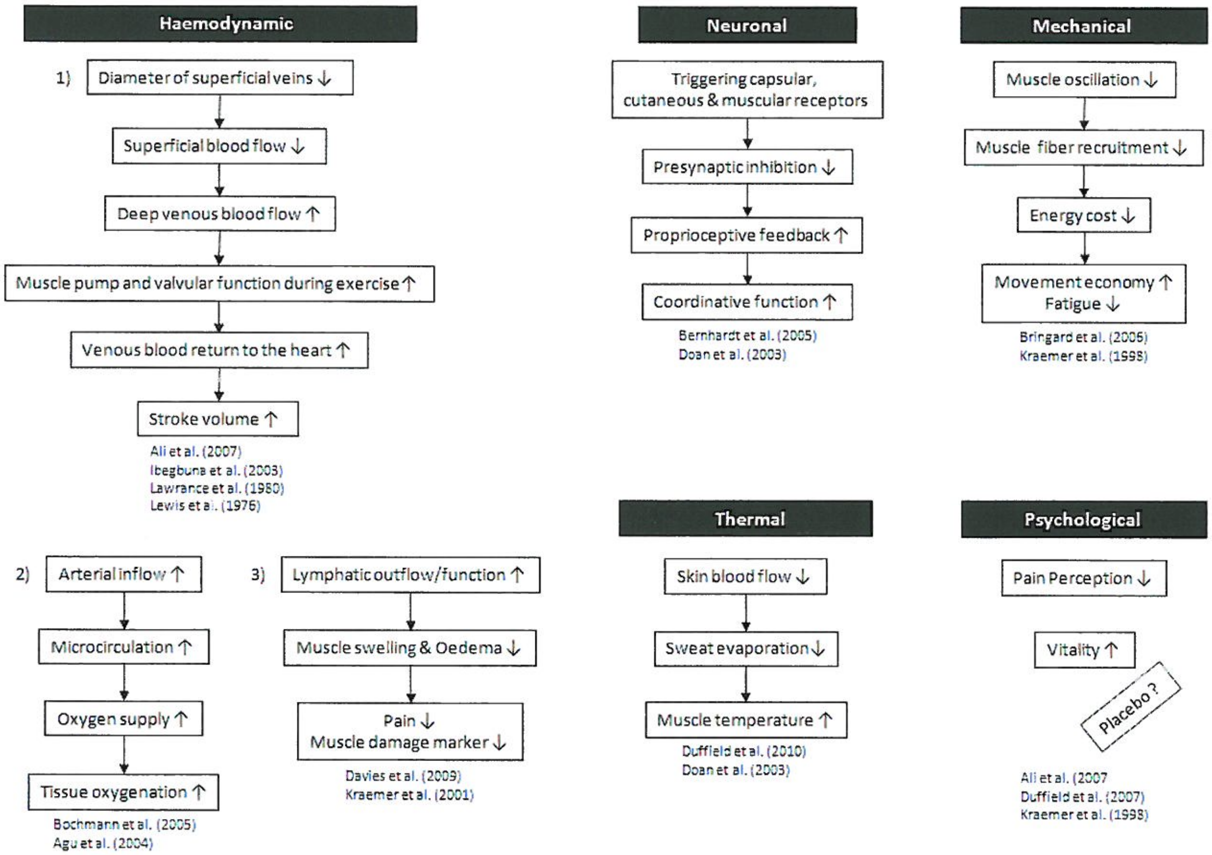

Figure 5 - Biological and psychological mechanisms underlying the application of compression clothing.

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Table 1. Studies investigating the effect of compression clothing on performance and recovery enhancement

Study	Characteristics of Participant			Characteristics of Compression Clothing		Performance (P)/ Recovery (R)	Study Protocol (Occasion when compression clothing was applied)	Effects of Compression Clothing
	Sample Size; Gender	Age	Athletic Category	Type, Graduated (G)	Applied Pressure [mmHg]			
Ali et al. (2011)	12; ♂+♀	33±10	Competitive runners (VO_{2max}: 68.7 ± 6.2 $mL·kg^{-1}·min^{-1}$)	Socks (G)	15, 21, 32	P, R	10-km time trial (during exercise)	TT↔, La↓, CP↕, Jump↕, RPE↕,
Dascombe et al. (2011)	11; ♂	28±10	Well-trained runners & triathletes (VO_{2max}: 59.0 ± 6.7 $mL·kg^{-1}·min^{-1}$)	Tights (G)	16-22, 14-19	P	1) Incremental running test 2) TTE at 90% of VO_{2max} $Temp_{Ambient}$: 22±2°C (during exercise)	VO_{2max}↑, TTE↔, VO_2↕, La↓, CP↔
Sperlich et al. (2011)	15; ♂	22±1	Well-trained runners & triathletes (VO_{2max}: 57.2 ± 4.0 $mL·kg^{-1}·min^{-1}$)	Socks (G)	10, 20, 30, 40	P	45-min treadmill running at 70% of VO_{2max} (during exercise)	VO_2↕, La↕, CP↕, SO_2↕, HR↑
Ali et al. (2010)	10; ♂	36±10	High-performance runners and triathletes (VO_{2max}: 70.4 ± 6.1 $mL·kg^{-1}·min^{-1}$)	Socks (G)	12-15, 23-32	P, R	40-min treadmill running at 80% VO_{2max} (during exercise)	VO_2↕, La↕, CP↕, RPE↕, Jump↕
Cabri et al. (2010)	6; ♂	31±7	Trained runner (5000-m best time: 1445 ±233-s)	Socks		P, R	Sub-maximal run (5000-m) at a velocity of 85% of the 5000-m best time (during exercise, 2-min after)	La↔, CP↑
Duffield et al. (2010)	11	21±3	Regional rugby players (3-4 training sessions w^{-1} and 1 $game·w^{-1}$)	Tights	10-30	P, R	Intermittent sprinting: 10-min (1 x 20-m sprint and 10 squat $jumps·min^{-1}$) (during exercise, 24-h after)	La↕, Jump↕, Sprint↕, DOMS↑, CK↕, Damage marker↕, HR↔, pH↑
Goh et al. (2010)	10; ♂	29±10	Recreational runners (VO_{2max}: 58.7 ± 2.7 $mL·kg^{-1}·min^{-1}$)	Tights (G)	9-14	P	20-min at 1st ventilator threshold followed by run to exhaustion at VO_{2max} at 10°C and 32°C (during exercise)	TTE↑

Table 1 (continued)

Study	Characteristics of Participant			Characteristics of Compression Clothing		Performance (P)/ Recovery (R)	Study Protocol (Occasion when compression clothing was applied)	Effects of Compression Clothing
	Sample Size; Gender	Age	Athletic Category					
Jakeman et al. (2010)a	8; ♀	21±2	Physically active (>3 times·w^{-1})	Tights (G)	15-17	R	Intermittent jumping: 10 x 10 drop-jumps (1 jump·10-sec^{-1}) with 1-min rest between sets (compression 12-h after exercise)	CK↕
Jakeman et al. (2010)b	8; ♀	21±2	Physically active (>3 times·w^{-1})	Tights (G)	15-17	R	Intermittent jumping: 10 x 10 drop-jumps (1 jump each 10-sec) with 1-min rest between sets (compression 12-h after exercise)	CK↕
Kraemer et al. (2010)	20; ♂+♀	23±3	Resistance-trained (>2 years)	WBC		R	Barbell resistance training workout: 8 exercises, 3 x 8-10-RM with 2-2.5-min rest between sets (compression 24-h after exercise)	DOMS↑
Rimaud et al. (2010)	8; ♂	27±1	Trained athletes (VO_{2max}: 53.3± 2.7 mL·kg^{-1}·min^{-1})	Socks (G)	12-22	P	Incremental cycling test (during exercise)	La↓
Sear et al. (2010)	8; ♂	21±1	Team amateur athletes (VO_{2max}: 57.5± 3.7 mL·kg^{-1}·min^{-1})	WBC		P	45-min high-intense interval treadmill running (during exercise)	TTE↑, VO_2↕, La↑
Sperlich et al. (2010)	15; ♂	27±5	Well-trained runners & triathletes (VO_{2max}: 63.7 ± 4.9 mL·kg^{-1}·min^{-1})	Socks Tights WBC	20	P	15-min treadmill running at 70% VO_{2max} followed by , running at to exhaustion at v_{max} of previous incremental test (during exercise)	VO_{2max}↑, TTE↓, VO_2↕, La↕, pO_2↕, SO_2↕, RPE↑
Davies et al. (2009)	11; ♂+♀	20±1	Netball and Basketball; University level	Tights (G)	15	R	Intermittent jumping: 5 x 20 drop-jumps with 2-min rest between sets (compression 48-h after exercise)	Jump↑, Sprint↕, Swelling↔, DOMS↕, CK↓, Damage marker↕
Higgins et al. (2009)	9; ♀	23±5	Elite netball players	Tights		P	Intermittent sprinting & jumping in a simulated netball game (4 x 15-min) (during exercise)	TTE↑
Houghton et al. (2009)	12; ♂	21±2	Field hockey (amateur) (VO_{2max}: 58.6 ± 5.5 mL·kg^{-1}·min^{-1})	Shorts & Shirts		P, R	Intermittent sprinting: 20-m sprints in a simulated hockey game (4 x 15-min) (during exercise)	Sprint↓, RPE↕, HR↓,

Table 1 (continued)

Study	Characteristics of Participant			Characteristics of Compression Clothing		Performance (P)/ Recovery (R)	Study Protocol (Occasion when compression clothing was applied)	Effects of Compression Clothing
	Sample Size; Gender	Age	Athletic Category	Type, Graduated (G)	Applied Pressure [mmHg]			
Kemmler et al. (2009)	21; ♂	39±11	Moderately trained runners (VO_{2max}: 52.0 ± 6.1 $mL·kg^{-1}·min^{-1}$)	Socks (G)	24	P	Incremental treadmill running test (during exercise)	TTE↑, VO_{2max}↑, La↔
Silver et al. (2009)	5; ♂	24±6	Highly strength trained 1-RM bench press (>125% BW)	Shirt		P	1-RM bench press, quantification of vertical and horizontal bar movements (during exercise)	Motor control↕
Duffield et al. (2008)	14; ♂	19±1	Regional rugby players	Tights		P, R	Intermittent sprinting: 10 & 20-m sprints in a simulated rugby game (4 x 15-min), $Temp_{Ambient}$: 16-18°C (compression 18-h after exercise)	Sprint↑, Strength & Power↕, CK↕, Temp↑
French et al. (2008)	10; ♂	24±3	Recreational/regional soccer and rugby players	Tights (G)	10-12	R	6 x 10 parallel squats at 100% BW + 11th repetition at 1-RM (compression 12-h after exercise)	CK↕, Damage marker↕
Montgomery et al. (2008)a	10; ♂	19±2	Regional basketball players 8-10 hours training·w^{-1}	Tights	18	R	3-day tournament with one 48-min game every day (compression 18-h after exercise)	Jump↑, Sprint↓
Montgomery et al. (2008)b	10; ♂	19±2	Regional basketball players 8-10 hours training·w^{-1}	Tights	18	R	3-day tournament with one 48-min game every day (compression 18-h after exercise)	Swelling↑, DOMS↑
Scanlan et al. (2008)	12; ♂	21±4	Amateur cyclists (VO_{2max}: 55.2 ± 6.8 $mL·kg^{-1}·min^{-1}$)	Tights (G)	9-20	P	1-h time trial (on cycling ergometer) (during exercise)	VO_{2max}↓, La↕
Ali et al. (2007)	14; ♂	22±1	Amateur runners 1) VO_{2max}: 56.1± 0.4 $mL·kg^{-1}·min^{-1}$ 2) VO_{2max}: 55.0± 0.9 $mL·kg^{-1}·min^{-1}$	Socks (G)	18-22	P, R	1) 2 x 20-m shuttle-runs (separated by 1-h) 2) 10-km time trial (road run) (during exercise)	TT↓, RPE↔, DOMS↔, HR↔,
Duffield et al. (2007)	10; ♂	22±1	Regional cricket players	WBC		P, R	1) Maximal distance throwing 2) Throwing accuracy 3) Intermittent sprinting: 20-m sprints·min^{-1} for 30-min $Temp_{Ambient}$: 15±3°C (during exercise, 24-h after)	La↑, SO_2↓, pO_2↓, Sprint↕, Strength & Power↑, RPE↓, HR↑, pH↓, CK↑, Temp↑

Table 1 (continued)

Study	Characteristics of Participant			Characteristics of Compression Clothing		Performance (P)/ Recovery (R)	Study Protocol (Occasion when compression clothing was applied)	Effects of Compression Clothing
	Sample Size; Gender	Age	Athletic Category	Type, Graduated (G)	Applied Pressure [mmHg]			
Bringard et al. (2006)	6; ♂	31±5	Well-trained runners (VO_{2max}: 60.9 ± 4.4 $mL \cdot kg^{-1} \cdot min^{-1}$)	Tights		P, R	1) Energy cost at 10, 12, 14, 16 $km \cdot h^{-1}$ (ambient temperature: 31°C) 2) 15-min treadmill running at 80% VO_{2max} $Temp_{Ambient}$: 23,6°C (during exercise)	VO_{2max}↓, RPE↑, Temp↑
Maton et al. (2006)	15; ♂	32±6	Healthy (type of sport not specified)	Stockings (G)	15-21	P, R	Maintaining 50% of 1-RM ankle dorsal flexion to exhaustion (during exercise, 10-min after)	TTE↓, Strength & Power↑
Trenell et al. (2006)	11; ♂	21±3	Recreational athletes (type of sport not specified)	Stockings (G)		R	30-min downhill treadmill walking (6$km \cdot h^{-1}$, 25% grade) (compression 48-h after exercise)	DOMS↑, Damage marker↕
Bernhardt et al. (2005)	13; ♂+♀	26± -	Healthy/active students (type of sport not specified)	Shorts		P, R	1) Active ROM, agility test, balance test, joint angle replication 2) 20-m sprint, vertical jump 3) 20-m shuttle run (during exercise)	VO_{2max}↔, Jump↔, Sprint↑, Motor control↓
Kraemer et al. (1996)	18; ♂+♀	21±3	Volleyball University players	Shorts		P	10 consecutive Counter-movement jumps (during exercise)	Jump↕
Berry et al. (1987)	6; ♂	23±5	Well-trained 1) VO_{2max}: 52.8 ± 8.0 $mL \cdot kg^{-1} \cdot min^{-1}$ 2) VO_{2max}: 59.9 ± 6.8 $mL \cdot kg^{-1} \cdot min^{-1}$	Socks (G)	8-18	P	1) Incremental treadmill running test to determine VO_{2max} 2) 3-min at 110% VO_{2max} (on cycling ergometer) (during exercise)	VO_{2max}↑, TT↔

Abbreviations: 1-RM, one repetition maximum; BW, body weight; WBC, whole body compression; TTE/TT, time to exhaustion/time trial; La, Blood lactate concentration; CP, Cardiac parameters (heart rate, cardiac output, cardiac index, stroke volume); Jump, vertical jumping exercise; RPE, rate of perceived exertion; VO_2, oxygen uptake; SO_2, oxygen saturation; pO_2, oxygen partial pressure; Sprint, short-duration sprinting; DOMS, delayed onset of muscle soreness; CK, creatine kinase; Damage marker, additional muscle damage marker; Swelling, muscle swelling; Strength & Power, strength and power exercise; Temp, body temperature; ↑, indicates a positive effect from compression; ↓, indicates a negative effect from compression; ↕ indicates contradictory results positive as well as negative effects from compression; ↔ indicates no effect from compression