



## Effect of Compression Garments on Physiological Responses After Uphill Running

by

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Limited practical recommendations related to wearing compression garments for athletes can be drawn from the literature at the present time. We aimed to identify the effects of compression garments on physiological and perceptual measures of performance and recovery after uphill running with different pressure and distributions of applied compression. In a random, double blinded study, 10 trained male runners undertook three 8 km treadmill runs at a 6% elevation rate, with the intensity of 75% VO<sub>2</sub>max while wearing low, medium grade compression garments and high reverse grade compression. In all the trials, compression garments were worn during 4 hours post run. Creatine kinase, measurements of muscle soreness, ankle strength of plantar/dorsal flexors and mean performance time were then measured. The best mean performance time was observed in the medium grade compression garments with the time difference being: medium grade compression garments vs. high reverse grade compression garments. A positive trend in increasing peak torque of plantar flexion (60°·s<sup>-1</sup>, 120°·s<sup>-1</sup>) was found in the medium grade compression garments: a difference between 24 and 48 hours post run. The highest pain tolerance shift in the gastrocnemius muscle was the medium grade compression garments, 24 hour post run, with the shift being +11.37% for the lateral head and 6.63% for the medial head. In conclusion, a beneficial trend in the promotion of running performance and decreasing muscle soreness within 24 hour post exercise was apparent in medium grade compression garments.

**Key words:** algometry, dynamometry, endurance athletes, external pressure, performance, recovery.

### Introduction

Athletes in various endurance sports disciplines wear compression garments with the anecdotal assumption that compression garments (CGs) help improve performance and/or facilitate recovery. The main hypotheses explaining the effect of CGs worn during exercise are its supposed abilities in decreasing vibrations, decreasing muscle microtrauma, and reducing oedema. The beneficial effects of CGs in a recovery phase are believed to be mediated by an improvement in a venous return of fresh blood and blood waste elimination (Kemmler et al., 2009). In practice, however, the justification for the practical usage of CGs by athletes is mainly based on limited subjective experience without a wide evidence based selection according to optimal patterns of pressure delivered.

With regard to distance running in particular, studies evaluating the use of compression stockings to improve performance have been ambiguous. To the best of our knowledge, there is only one study that revealed exercise performance improvements (Kemmler et al., 2009), with others showing non-affected running performance (Ali et al., 2011; Sperlich et al., 2011). Most recently, it was concluded that compression clothing had no significant impact on performance variables during distance running and other endurance disciplines (e.g. ice speed skating, triathlon, cross country skiing, and kayaking) (Engel et al., 2016).

It has been now clearly demonstrated that wearing CGs is beneficial for performance recovery by enhancing recovery from muscle

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damage (Jakeman et al., 2010) and reducing self-reported perceptions of recovery like post-exercise muscle soreness (Hill et al., 2014). Moreover, a recent meta-analysis revealed that wearing of CGs: (1) reduced the severity of the delayed onset of muscle soreness (DOMS), (2) promoted recovery of muscular strength and muscular power, (3) facilitated elimination of lactate, and (4) affected systemic creatine kinase activity (Hill et al., 2014). Not much is however known about the pattern of the pressure applied that promotes the aforementioned recovery processes (MacRae et al., 2011).

A number of events involved in the damage-inflammation-recovery process are initiated very quickly following any damage incurred by running. As demonstrated by previous research (Bovenschen et al., 2013), beneficial effects of CGs after distance running are visible mainly in an early phase of the recovery period. Yet, there is huge heterogeneity in garment wear time by athletes during recovery (MacRae et al., 2011). In running events, CGs are used by athletes during training to limit cumulative fatigue and symptoms associated with mild exercise-induced muscle damage. Associated force deficits may limit optimal performance in subsequent days. It was found that wearing CGs 5 hours post-exercise helped to recover contractile properties of muscles within 24 hours (Perrey et al., 2008). Besides an impact of wear time, the range of delivered pressure is also very high among studies ranging from 1-34 mmHg at the ankle and 8-27 mmHg at the calf (Beliard et al., 2015). To date, the ideal compression pressure required to be beneficial to performance and recovery has not been defined (Hill et al., 2015).

A common issue among CGs used in sports is related to the direction of the pressure. Gradual compression indicates that the applied pressure is highest when distal and it decreases proximally. This relates primarily to circulatory roles such as the reduction of venous pooling and augmentation of venous blood flow velocity (MacRae et al., 2011). Not much is known about the effect of various pressure distributions, e.g. reverse graduation (compression pressure increasing proximally). Such examples of lower limb reverse CGs are very commercial and widely available to athletes without any scientific evidence to support their effectiveness. To the

best of our knowledge, the effect of reverse compression pressure distribution has not been studied and has not been reported by researchers. Furthermore, many of studies even failed to report the pressure applied (Hill et al., 2015). Despite the increasing number of scientific papers, limited practical recommendations related to wearing CGs for athletes may be found in the literature at the present time.

We attempted to identify the effect of CGs pressure distribution with graduated (LOW-GC: low grade compression garments, MED-GC: medium grade compression garments) and reverse-graduated compression (HIGH-RGC: high reverse grade compression garments) on physiological and perceptual measures of performance and recovery.

## Methods

### Participants

Ten well trained male runners volunteered to participate in the study (age  $24.8 \pm 3.45$  years; body mass  $74.11 \pm 8.63$  kg; body height  $1.81 \pm 0.08$  m; body mass index  $22.5 \pm 1.11$  kg·m<sup>2</sup>; body fat  $9.96 \pm 3.11\%$ ;  $VO_{2max}$   $62.89 \pm 7.68$  mL·kg<sup>-1</sup>·min<sup>-1</sup>). All of them were well-trained endurance runners at the time of the study (weekly running distance  $43.0 \pm 5.4$  km; 10 km best time  $38.0 \pm 1.5$  min). All participants gave written consent before participating in the study.

The study was approved by the university ethics committee and was in accordance with the Declaration of Helsinki for Human Research. All experimental procedures were conducted in accordance with the appropriate ethical guidelines (Harriss and Atkinson, 2015). Inclusion criteria were: (1) the best personal time for 10 km less than 40 minutes, (2) the minimum training load more than 35 km·week<sup>-1</sup>, and (3) no history of leg injuries within the last year and no history of vascular disease.

### Study design

The experiment was designed as a double blind study for the elimination of researcher bias. Each participant visited the laboratory 9 times in three blocks for measurements. Each block of measurements lasted three days and consisted of an experimental running test followed by 24 and 48 hour additional measurements. A three day wash-out period was kept between testing blocks. Two weeks before the experimental protocol,

participants undertook an incremental running test until exhaustion. On the day before the experimental test and the two days that followed, participants were asked not to attend any sort of muscle therapy such as ice baths, cold water immersion and massage, and they were also told not to perform any exercise. Additionally, participants were asked not to take any anti-inflammatory medication. Before the experimental testing protocol, all participants were instructed to be hydrated ad libitum and to refrain from strenuous exercise and from consuming alcohol or caffeine for 24 hours.

### **Measures**

#### *Preliminary $VO_{2max}$ test*

A ramp test was conducted on a standard treadmill ergometer (Lode Katana). Gas exchange was continuously measured by a cardiopulmonary metabolic system with breath by breath technology (METALYZER<sup>®</sup>3B, CORTEX). Calibration of the gas analyser was performed before each test following manufacturer's instructions.

#### *Pain tolerance measurement*

Algometry was used in quantifying local muscle pain and tenderness. Measurements contained findings of the pain threshold on calf muscles with a computerized pressure algometer (The AlgoMed from Medoc Company). It was tested on the dominant leg of each participant. Each participant was in a prone position with the support of the tibia. The researcher marked two circles on the dominant leg with a pen for consistency since each circle contained four different points for algometry measurement. One circle was 14 cm under the popliteal fossa which is a shallow depression located at the back of the knee joint on the medial. The other circle was drawn on the lateral head of the gastrocnemius muscle. Subsequently, the researcher pressed into the marked points with increasing pressure until the participant stopped the test with the response unit handle. Algometry was measured before the test as well as 24 and 48 hours after the experiment.

#### *Ankle strength measurements*

Before testing, each participant undertook a 5 min warm up that involved walking and running at a self-selected pace. Muscle strength evaluation was performed using an isokinetic dynamometer (Humac Norm) in a standard

position according to the Humac Norm System and previous research with the hip and knee flexed to 60° and the lower leg that was supported in a horizontal position (Webber and Porter, 2010). To stabilise this position, straps were fitted around the participant's ankle, knee and pelvis. Dorsiflexion and plantarflexion testing of the dominant leg was conducted in the supine position on the adjustable bench in barefoot conditions (Picture 1). The axis of the dynamometer was aligned with the plantar flexion and dorsiflexion axis of the ankle joint. The range of motion was set to 10° of dorsiflexion and 20° of plantar flexion to get familiar with testing procedures. This was undertaken before the first test. The movement started from the foot in 90° dorsal flexion. Tests were performed under isokinetic conditions to evaluate power and torque at different velocities and in different isometric conditions in order to measure the maximum peak torque on the dominant leg of the participant. The low velocity was set at 60°·s<sup>-1</sup>, and the high velocity at 120°·s<sup>-1</sup>. Each movement was repeated six times at two velocities, with rest intervals of 60 s between each angular velocity. Verbal encouragement was given throughout testing. The maximum peak torque (PT) was found as the highest value among five contractions for each test condition. Ankle strength was assessed before, 24 and 48 h after the exercise protocol.

#### *Analysis of creatine kinase (CK) activity*

We used capillary blood samples to assess CK activity. Capillary sampling is a simpler and less invasive sampling method than venous puncture and frequently used in repeated sampling over days (using a described sampling approach, a blood sample does not change standard assay protocols). Furthermore, studies proved a high correlation between total CK measured in capillary and venous blood samples (Knoblauch et al., 2010; Nunes et al., 2006).

After cleaning the fingertip with sterile alcohol and a swab, a finger prick was made using a lancet (ACCU-CHEK<sup>®</sup> Safe-T-Pro Plus lancet, depth was set to 2.3 mm). Afterwards, 32 µl of blood was collected into a lithium-heparinised capillary tube and immediately transferred to a Reflotron CK test strip and analysed using a Reflotron Plus diagnostic device (Roche Diagnostics, Basel, Switzerland). Analysis of CK

activity was repeated at 24 and 48 h post exercise protocol.

#### *Compression sleeves (CS)*

We used three CGs with different compression pressure. Before researchers received the sleeves from the manufacturer, every pair of sleeves was coded with three randomly chosen letters without meaning in order to prevent the researchers and the participants from knowing the compression pressure. On the day of testing, each participant randomly chose one pair of sleeves without knowing its compressed value. Two of them were designed as gradual CS with the highest pressure around the ankle and gradually decreasing pressure to the knee. One of them was designed with the lowest pressure around the ankle and with increasing pressure to the calf (Table 1). The correct size for each participant was determined by the measurements of leg circumference at the widest part of the calf. Each pair of CS was designed in the same appearance and white color to prevent any placebo effects. The pressure values were measured in vitro and explicitly reported by the manufacturer to ensure their validity. The measuring device used was MST MK IV SALZMANN AG from ST. GALLEN, Switzerland. The required external pressure of tested CS was achieved by calf circumference measurements.

#### *Rating of perceived exertion (RPE)*

RPE data was collected during each testing session. The participants were asked to rate their perceived exertion on the Borg 6–20 scale; it was recorded in 10, 20, 30, and 40 min intervals during the test.

#### *Experimental day procedures*

Participants arrived to the laboratory at the same time for each measurement, between 8 and 11 am. First, the resting seated position was precisely controlled and measured for 15 min before taking capillary blood samples for CK analyses. The next step contained the measurement of the pain threshold on the calf muscle with the algometer. Afterwards, the participants warmed up for 5 min before ankle strength measurements. Then they rested for 15 min before the experimental test on the treadmill. During the rest, under the supervision of the researcher the participants put on the CGs on both calves to ensure correct fitting. The participants

then warmed up for 5 minutes with a self-selected initial running speed. The average speed was between 10 and 11 km·h<sup>-1</sup> with a 1% elevation rate. The testing protocol was then set up at 8 km running on a treadmill with a 6% elevation rate at the intensity of 75% of personal VO<sub>2max</sub>. Figure 1 illustrates the study design with the schedule of each measurement. CS were worn during the experiment and also for 4 hours after the exercise protocol.

#### *Statistical analyses*

Data was calculated with conventional procedures and presented as mean values and standard deviation. Data was checked for normality as well without further transformation being necessary. Statistical significance was reported when  $p < 0.05$ . All analyses were conducted using the Statistica 12.0 program. A paired t-test for dependent samples was used to analyse the obtained data.

## **Results**

The overall results of performance, physiological and perceptual data are presented in Tables 2 - 4, and Figures 2 and 3. There were no statistical differences for all testing conditions (LOW-GC, MED-GC, HIGH-RGC) in plantar flexion 60°·s<sup>-1</sup>, dorsal flexion 60°·s<sup>-1</sup>, or dorsal flexion 120°·s<sup>-1</sup>. However, the lowest reduction in peak torque was found in the MED-GC between pre vs. 24 hour post experiment ( $p = 0.0143$ ). This trend was also found between pre vs. 48 hour post experiment in the MED-GC (Table 2). Contrary to this, peak torque of the plantar flexors (120°·s<sup>-1</sup>) in the LOW-GC and the HIGH-RGC continuously decreased.

There were no statistical differences for all testing conditions (LOW-GC, MED-GC, HIGH-RGC) in peak pressure tolerance for the lateral head of the gastrocnemius (Table 3). The only statistical differences observed were for the LOW-GC between the results taken 24 and 48 hours post exercise in the variable of the medial head of the gastrocnemius ( $p = 0.0082$ ).

The blood values of creatine kinase activity (Table 4) demonstrate that experimental procedures were sufficient enough to induce physiological responses related to a delayed onset of muscle soreness. According to the results, the rise in blood values of the CK activity in the MED-GC and the HIGH-RGC discontinued or even

decreased 24 hour vs. 48 hour post exercise.

CGs effect on running performance was not significantly different (Figure 2). Comparing all three conditions, the lowest median and average performance time was found in the MED-GC. The median time performance for the MED-GC was 1.9% and 1.1% better than in the LOW-GC and the HIGH-GC, respectively.

CGs effect on the rate of perceived exertion during experimental running was not significantly different. The values of the median and average show (Figure 3) that perceived exertion during experimental running was negatively related to the HIGH-RGC.

**Table 1**

*Pressure applied by compression sleeves at the ankle and below the knee*

Type of elastic compression sleeves (fabric characteristics)	Pressure at the ankle (mmHg)	Pressure below the knee (mmHg)
LOW-GC (88% nylon, 12% elastane Lycra)	18	15
MED-GC (82% nylon, 18% elastane Lycra)	25	21
HIGH-RGC (75% polyamide, 25% elastane Lycra)	18	24

LOW-GC (low grade GC), MED-GC (medium grade GC); HIGH-RGC (high-grade reverse GC)

**Table 2**

*Descriptive data for plantar and dorsal flexion peak torque pre and post exercise (mean  $\pm$  SD)*

Variables		LOW-GC	MED-GC	HIGH-RGC
Plantar flexion 60°·s <sup>-1</sup> (Nm)	Pre-test	100.8 $\pm$ 26.0	96.6 $\pm$ 31.7	95.7 $\pm$ 25.7
	24 h post	93.4 $\pm$ 25.7	92.7 $\pm$ 35.2	93.2 $\pm$ 26.4
	48 h post	92.1 $\pm$ 27.3	94.4 $\pm$ 39.5	90.3 $\pm$ 29.0
<i>p</i> value pre vs. 24 h post		0.0652	0.1824	0.6605
<i>p</i> value 24 h post vs. 48 h post		0.7846	0.3427	0.4687
Plantar flexion 120°·s <sup>-1</sup> (Nm)	Pre-test	162.6 $\pm$ 55.8	151.0 $\pm$ 64.4	155.6 $\pm$ 49.1
	24 h post	155.3 $\pm$ 45.1	148.5 $\pm$ 64.5	150.8 $\pm$ 43.7
	48 h post	148.3 $\pm$ 52.3	153.9 $\pm$ 68.3	143.0 $\pm$ 52.1
<i>p</i> value pre vs. 24 h post		0.291040	<b>0.0143*</b>	<b>0.0184*</b>
<i>p</i> value 24 h post vs. 48 h post		0.876913	0.0693	0.4838
Dorsal flexion 60°·s <sup>-1</sup> (Nm)	Pre-test	22.2 $\pm$ 3.0	22.5 $\pm$ 4.1	22.1 $\pm$ 4.1
	24 h post	22.4 $\pm$ 2.0	22.3 $\pm$ 3.6	23.0 $\pm$ 3.9
	48 h post	22.8 $\pm$ 3.1	23.7 $\pm$ 3.5	23.1 $\pm$ 3.8
<i>p</i> value pre vs. 24 h post		0.7640	0.8321	0.3237
<i>p</i> value 24 h post vs. 48 h post		0.7518	0.1529	0.8402
Dorsal flexion 120°·s <sup>-1</sup> (Nm)	Pre-test	30.6 $\pm$ 4.1	29.6 $\pm$ 6.3	29.6 $\pm$ 6.2
	24 h post	30.4 $\pm$ 4.0	29.7 $\pm$ 5.4	31.1 $\pm$ 5.3
	48 h post	29.8 $\pm$ 4.7	31.8 $\pm$ 7.3	31.0 $\pm$ 4.6
<i>p</i> value pre vs. 24 h post		0.8363	0.9127	0.2729
<i>p</i> value 24 h post vs. 48 h post		0.5910	0.0935	0.9342

\* *p* < 0.05

**Table 3**

*Calf muscle peak pressure tolerance by athletes pre- and post-exercise using computerized muscle algometry (mean  $\pm$  SD)*

Variables		LOW-GC	MED-GC	HIGH-RGC
LAT (kPa)	Pre-test	667.77 $\pm$ 234.21	587.83 $\pm$ 233.03	555.67 $\pm$ 237.23
	24 h post	624.25 $\pm$ 189.57	654.72 $\pm$ 290.83	568.01 $\pm$ 216.88
	48 h post	665.85 $\pm$ 233.51	673.35 $\pm$ 285.94	589.68 $\pm$ 198.14
<i>p</i> value pre vs. 24 h post		0.4248	0.2418	0.8483
<i>p</i> value 24 h post vs. 48 h post		0.4034	0.5596	0.7365
MED (kPa)	Pre-test	445.99 $\pm$ 135.22	403.08 $\pm$ 103.55	352.42 $\pm$ 125.29
	24 h post	430.41 $\pm$ 121.26	429.83 $\pm$ 141.95	376.53 $\pm$ 107.19
	48 h post	493.35 $\pm$ 134.27	429.25 $\pm$ 148.53	431.89 $\pm$ 124.90
<i>p</i> value pre vs. 24 h post		0.6033	0.2050	0.4128
<i>p</i> value 24 h post vs. 48 h post		0.0082*	0.9829	0.0613

\* *p* < 0.05

LAT, lateral head of gastrocnemius; MED, medial head of gastrocnemius

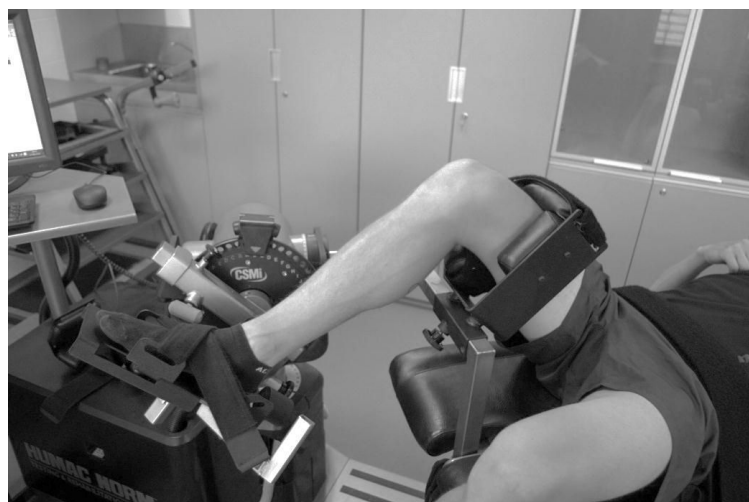
**Table 4**

*Descriptive data for creatine kinase (CK) activity pre and post exercise (mean  $\pm$  SD)*

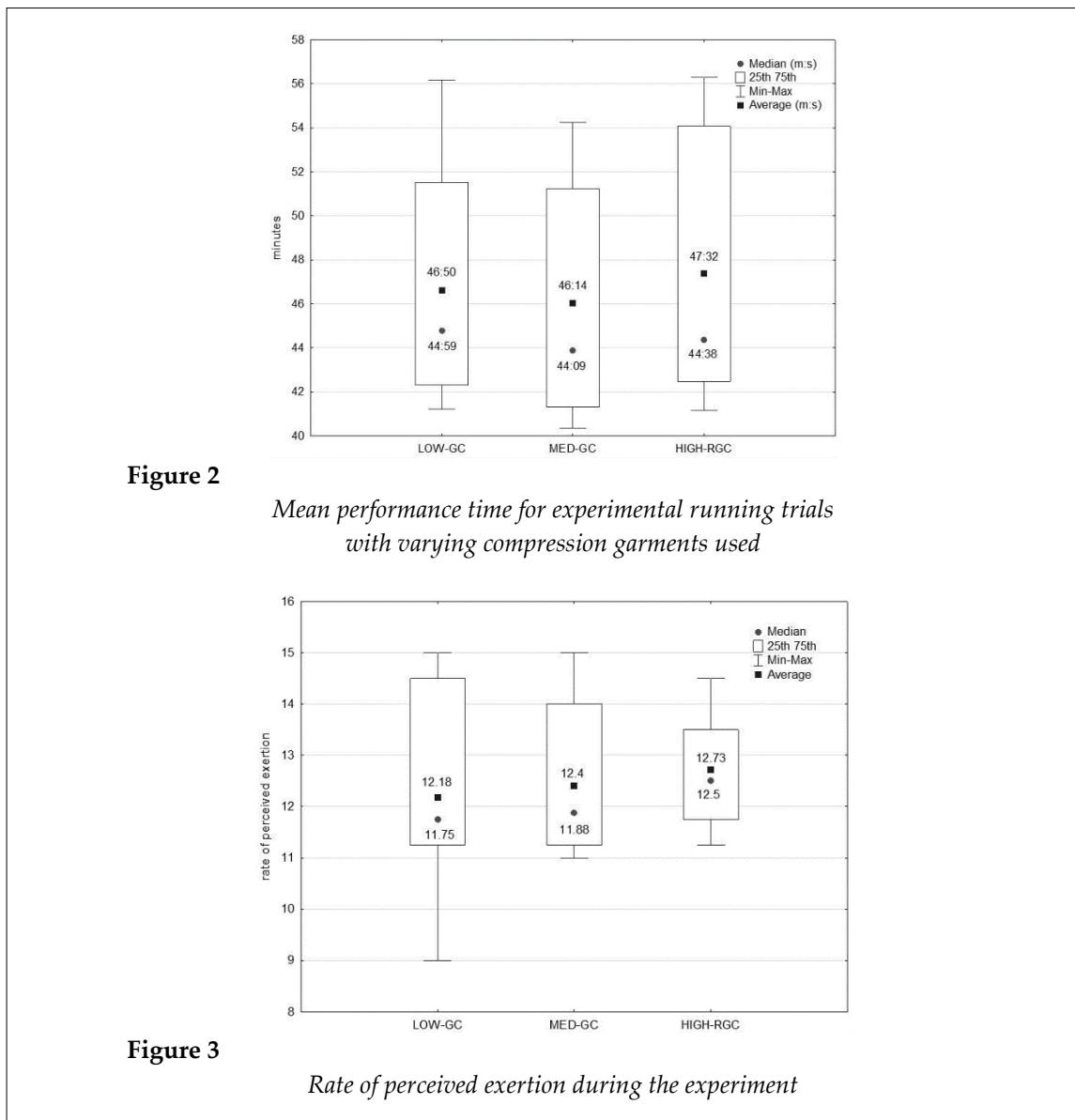
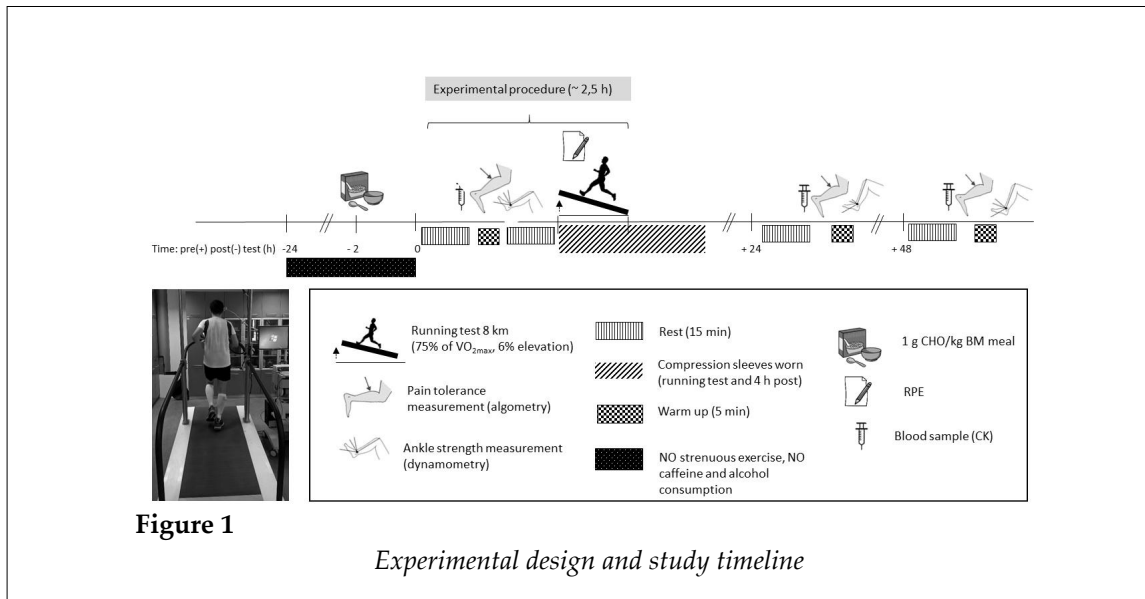
Variable		LOW-GC	MED-GC	HIGH-RGC
CK activity (U/L)	Pre-test	253.1 $\pm$ 118.2	207.5 $\pm$ 100.0	264.9 $\pm$ 144.7
	24 h post	302.0 $\pm$ 126.8	274.9 $\pm$ 113.9	377.0 $\pm$ 157.8
	48 h post	338.0 $\pm$ 276.1	275.0 $\pm$ 132.6	291.4 $\pm$ 147.5
<i>p</i> value pre vs. 24 h post		0.1138	<b>0.0461*</b>	0.3427
<i>p</i> value 24 h post vs. 48 h post		0.1138	0.1130	<b>0.0268*</b>

\* *p* < 0.05

U/L; units per liter

**Picture 1**

*Dynamometry measurements (plantar-dorsal flexion)*



## Discussion

The primary aim of this study was to examine the effect of CGs on physiological and perceptual measures of performance and recovery after uphill running in a laboratory setting. The running test which was a 8 km run on a treadmill with a 6% elevation rate at the intensity of 75% of personal peak oxygen uptake was intense enough to induce changes in CK activity, pain tolerance levels and ankle strength.

The present data is consistent with this reported in the literature (Ali et al., 2007; Ali et al., 2010; Bovenschen et al., 2013; Kemmler et al., 2009). Our findings showed that using the MED-GC with the compression at the ankle at 25 mmHg and at the knee at 21 mmHg had the highest positive impact on performance and recovery. For a better understanding, the key findings are presented separately.

### *Compression pressures applied*

Knowing the applied pressure and its characteristics (increasing or decreasing pressure to the calf) is important to identify the potential benefits in the area of sport performance and recovery (Kraemer et al., 2001). We used the compression grades with the pressure at the calf with the circumference at the widest part and designated as low (15 mmHg), medium (21 mmHg), and high (25 mmHg). Characteristics of CGs used in our study refer to commercially available products. Based on medical findings, earlier research recommended applying graduated compression clothing, with pressure decreasing continuously from distal to proximal and therefore the majority of studies so far have used such garments (Perrey et al., 2008).

This is the first study that evaluated the effect of reverse graduated compression with pressure decreasing continuously from the proximal to the distal part of the calf. However, there appears to be a high variation in pressure exerted by commercially available CGs (Hill et al., 2015) and we believe that athletes are not aware of the pressure applied with these CGs or even the pressure distribution. We did not include a no-garment condition to control for placebo effects; however, we used different garments that were made to look identical and they were randomly administered before each trial to minimize placebo effects (Perrey et al., 2008). We retrospectively found via a questionnaire that

athletes recognized with difficulty the garment they were given. Only 36% of administered garments were identified. However, the LOW-GC garments were correctly recognized by seven athletes, in contrast to the MED-GC and HIGH-RGC, with 3 and 2 athletes recognizing them, respectively. Despite that fact that the LOW-GC garments were noticeably less tight than the MED-GC and HIGH-RGC, the difference was not considerably high since it was only by 6 and 9 mmHg, respectively. The difference would have been even greater using a placebo and a majority of athletes would have been able to recognize them. Therefore, the necessity of placebo garment usage needs further consideration.

### *Ankle strength measurements*

The power of the ankle dorsal and plantar flexors was tested prior, 24 and 48 hours after exercise. Tests were performed under isokinetic conditions to measure peak torque at different velocities: low velocity at 60°·s<sup>-1</sup> and high at 120°·s<sup>-1</sup>. According to the results (Table 2), we found a positive trend in the increase of peak torque of the plantar flexion 60°·s<sup>-1</sup> in the group of athletes that tested the MED-GC. The difference in numbers between the 24 and 48 hour post experiment was +1.83%. Along the same lines, a positive trend was also observed with the MED-CD in the peak torque of the plantar flexion 120°·s<sup>-1</sup> with the difference in numbers being +3.63%. Contrary to the aforementioned results, we showed the decrease of maximum peak torque of the plantar flexions 60°·s<sup>-1</sup> and 120°·s<sup>-1</sup> for the group of athletes that tested the LOW-GC and HIGH-RGC. Here are the results: LOW-GC: 24 h post vs. 48 post; plantar flexion 60°·s<sup>-1</sup> -1.4%; 24 h post vs. 48 post; plantar flexion 120°·s<sup>-1</sup> -3.51%, and HIGH-RGC: 24 h post vs. 48 post; plantar flexion 60°·s<sup>-1</sup> -3.12%; 24 h post vs. 48 post plantar flexion 120°·s<sup>-1</sup> -5.18%. The assessment of dorsiflexion, at 60°·s<sup>-1</sup> and 120°·s<sup>-1</sup>, did not show any statistical significance or any mentionable increasing or decreasing maximum peak torque. The possible reason for this finding can be connected with the range of motion which was only 10°. Concurrently, we are strongly convinced that the other possible reason of the aforementioned results is that the plantar flexion is used predominantly for uphill running. This information is of great practical importance for runners.

### *Running test performance*

No effects of wearing different grades of



GCs on 8 km uphill running performance (6% incline, 75% of  $VO_{2max}$ ) and recovery within 24 and 48 h post exercise were observed. We found that the time to complete the running test was not significantly affected by the selected CGs. The mean performance time was lowest using medium compression (46:14), and highest using high compression (47:32). The time difference of 81 s may be of practical or physiological importance in real sport events (Figure 2), however, there was no statistically significant difference. We may then speculate that wearing CGs with the HIGH-RGC (higher in the calf area than in the ankle) is not beneficial for performance. This corresponds with the study of Lawrence and Kakkar (1980) where authors reported that high compression (approximately 30 mmHg at the calf) may be detrimental to performance because of an impaired blood flow and a limited venous return. Our findings are generally consistent with other running studies in which well-trained athletes did not gain any performance benefits from wearing CS during prolonged running (Ali et al., 2011; Areces et al., 2015; Vercruyssen et al., 2014). To the best of our knowledge, this is the first study describing the effects of lower limb CGs on controlled uphill running in a laboratory setting.

#### *Analysis of CK activity*

The experimental testing protocol induced changes at the muscular levels in the post-exercise period (Table 4). CK values peaked 24 hours after the exercise protocol in the group of athletes with the MED-GC and HIGH-RGC. These are the results:  $274.9 \pm 113.9$  U/L;  $377.0 \pm 157.8$  U/L. After 48 hours, the highest decrease was observed in the group of athletes that tested the HIGH-RGC. The change between 24 and 48 hours post experiment was 22.8% and it was a significant difference ( $p = 0.0268$ ). The results were markedly different in the group of athletes with the LOW-GC (+11.9%) and MED-GC (0.04%).

#### *Rating of perceived exertion*

RPE values were recorded in 10, 20, 30, and 40 min intervals during the test. According to the results, no significant difference occurred between the LOW-GC, MED-GC, and HIGH-RGC (Figure 3). As we mentioned above, this can also be connected with the fact that the MED-GC and HIGH-RGC were correctly recognized by only 3 MED-GC and 2 HIGH-RGC athletes.

#### *Pain tolerance measurement*

The pain threshold in calf muscles was evaluated with a Computerized Pressure Algometer. The applied pressure was continuous and at a constant rate on the athlete's selected points of the knee to obtain reliable results. The results indicate (Table 3) increasing pain tolerance in the group of athletes with the MED-GC on the medial and the lateral head of the gastrocnemius muscle. The difference between the pre-test and 24 hour post experiment was +11.37% for the lateral head and 6.63% for the medial head. There was a considerable difference in the groups of athletes with the LOW-GC and HIGH-RGC. The results are the following: LOW-GC pre-test vs. 24 hour post, lateral head -6.52%; HIGH-RGC pre-test vs. 24 hour post, lateral head +2.20%; LOW-GC pre-test vs. 24 hour post; medial head -3.50%; HIGH-RGC pre-test vs. 24 hour post, medial head +6.84%. These findings are consistent with the ones presented by Sperlich et al. (2011). We are convinced that muscle soreness may be reduced by compression sleeves because of their ability to hold muscle tissue structure in place during running. This also allows less cellular damage and reduces swelling. Even though the presented data is not statistically significant under any condition (LOW-GC, MED-GC, HIGH-RGC), the crux of the matter is in the applied pressure. Our assumption is based on differences between mean value and percentage differences between conditions. This is in contrast to the study of Beliard et al. (2015) which resulted in no apparent relationship between the effects of compression garments worn during or after exercise and the pressures applied. If the information in this study is true, then other factors exist which explain the efficacy of compression garments and these factors remain to be researched.

The present study had no control group. Application of a placebo in the control group (CS with no or minimum pressure) might help eliminate any potential bias and allow to better understand the effect of different CS. Another limitation of the study is the small sample size and running experience of participants. We suppose that well-trained runners have a more developed calf muscle pump function. Subsequently, the effect of CS can be lower because of running experience. It would be interesting to compare the novice and competitive

runners. Further research would certainly bring interesting conclusions.

## Conclusions

In conclusion, a potential performance effect from wearing lower limb compression garments during uphill running in well-trained runners is independent of the pressure applied. However, based on statistically non-significant ~80 s time difference between graduated compression (21 mmHg) and high compression (25 mmHg) with reverse graduation, it may be assumed that graduated compression with pressure increasing distally is rather detrimental to performance. There was, however, a beneficial trend in the promotion of ankle muscle performance, the clearance of CK activity, and the rate of perceived exertion in at least one instance.

It was apparent in post exercise for the garment with the medium-grade graduated compression with the pressure at the ankle of 25 mmHg and with the pressure below the knee of 21 mmHg. This may be of practical importance especially for those training on a daily basis. On the other hand, there was a high detrimental effect observed in the grade reverse compression, which provided pressure at the ankle of 18 mmHg and pressure below the knee at 24 mmHg. This was observed in all variables excluding CK.

The effects of pressure variation and distribution cannot be viewed as complex, but rather as very selective in terms of being beneficial or even detrimental under various conditions.

## Acknowledgements

This article was written at the Masaryk University as part of the project The influence of compression sleeves on performance and recovery 1212/2015 with the support of the Specific University Research Grant, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2016.

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