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ORIGINAL ARTICLE

Compression stockings do not improve muscular performance during a half-ironman triathlon race

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Abstract

Purpose This study aimed at investigating the effectiveness of compression stockings to prevent muscular damage and preserve muscular performance during a half-ironman triathlon.

Methods Thirty-six experienced triathletes volunteered for this study. Participants were matched for age, anthropometric data and training status and placed into the experimental group ($N = 19$; using ankle-to-knee graduated compression stockings) or control group ($N = 17$; using regular socks). Participants competed in a half-ironman triathlon celebrated at 29 ± 3 °C and 73 ± 8 % of relative humidity. Race time was measured by means of chip timing. Pre- and post-race, maximal height and leg muscle power were measured during a countermovement jump. At the same time, blood myoglobin and creatine kinase concentrations were determined and the triathletes were asked for perceived exertion and muscle soreness using validated scales.

Results Total race time was not different between groups (315 ± 45 for the control group and 310 ± 32 min for the experimental group; $P = 0.46$). After the race, jump height (−8.5 ± 3.0 versus −9.2 ± 5.3 %; $P = 0.47$) and leg muscle power reductions (−13 ± 10 versus −15 ± 10 %; $P = 0.72$) were similar between groups. Post-race myoglobin (718 ± 119 versus 591 ± 100 μg/mL; $P = 0.42$) and creatine kinase concentrations (604 ± 137 versus 525 ± 69 U/L; $P = 0.60$) were not different between groups. Perceived muscle soreness (5.3 ± 2.1 versus 6.0 ± 2.0 arbitrary units; $P = 0.42$) and the rating of perceived effort (17 ± 2 versus 17 ± 2 arbitrary units; $P = 0.58$) were not different between groups after the race.

Conclusion Wearing compression stockings did not represent any advantage for maintaining muscle function or reducing blood markers of muscle damage during a triathlon event.

Keywords Compression garments · Jump performance · Endurance athletes · Myoglobin · Creatine kinase · Muscle damage

Abbreviations

CK	Creatine kinase
CMJ	Countermovement vertical jump
EDTA	Ethylenediaminetetraacetic acid
ES	Effect size
F2	Second peak of ground reaction force during the landing
LDH	Lactate dehydrogenase
SD	Standard deviation
VO_2	Oxygen uptake

Introduction

Triathlon is an endurance sport characterized by the continuous and sequential completion of swimming, cycling, and running sectors over various distances (Lepers et al.

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2013). During triathlon competitions, participants contest for the fastest overall race time, including timed transitions between the swim, bike, and run sections. Triathlon events are performed outdoors and participants are subjected to the stress imposed by the environmental conditions. Previous investigations have determined that age, anthropometry, nutritional strategies and physical training before the race are the main factors related to success during triathlon competitions (Houston et al. 2011; Knechtle et al. 2011; Lepers et al. 2010). However, additional strategies can be used on the day of the race to maximize endurance performance.

Recently, muscle fiber breakdown has been suggested as one of the most important factors for the lessening in the muscular performance during a triathlon race (Del Coso et al. 2012a). Running (Del Coso et al. 2012b; Schiff et al. 1978) and cycling (Bessa et al. 2008) endurance activities may cause damage to the structure of the muscle fiber. The causes for exercise-induced muscle damage in endurance events can be related to the continuous eccentric and concentric muscle actions or to metabolic deficiencies such as decreased action of Ca^{2+}/adenosine triphosphatase (Tee et al. 2007). Irrespective of the mechanism, exercise-induced muscle damage negatively affects the capacity of the muscle to generate strength (Clarkson and Sayers 1999) which in turn might affect performance during cycling and running sectors of a triathlon. Preventing muscle damage during a triathlon race may represent a meaningful advantage for muscular and overall performance (Del Coso et al. 2012a).

In the clinical setting, the use of graduated compression garments is a therapy to enhance venous return in patients with chronic venous insufficiency (Hamdan 2012). The utilization of compression garments has also been adopted for athletes due to their potential benefits for physical performance and recovery (de Glanville and Hamlin 2012). Compression garments apply mechanical pressure to the body and they compress and support underlying tissues (MacRae et al. 2011). Compression therapy in sports is mainly focussed on venous return and the main benefits of compression clothing are related to improved blood circulation during exercise (Sperlich et al. 2013). Besides, the use of compression stockings attenuates the muscular oscillations during repeated jumps (Kraemer et al. 1998) and they might be used to reduce muscle damage during the cycling and running sections of a triathlon race. However, preliminary data about the effectiveness of compression garments to prevent muscle damage are unclear. It has been found that compression tight garments are effective for the recovery of muscle performance and to lessen muscle soreness after 100 plyometric drop jumps that induced muscle damage in young active females (Jakeman et al. 2010a, b). In contrast, the use of compression stockings did not significantly change running performance during prolonged trail running exercise (Vercruyssen et al. 2012), a netball-specific circuit (Higgins et al. 2009), muscle soreness after maximal treadmill running (Ali et al. 2010) or the blood markers of muscle damage after 6 × 10 parallel squats at 100 % body weight (French et al. 2008). The differences in the study designs and clothing styles preclude obtaining definite effects of compression garments on performance (Sperlich et al. 2011). In addition, despite the theoretical benefits of compression clothing, there is little evidence about the effects of wearing compression garments on prolonged endurance events (Born et al. 2013).

The aim of this study was to investigate the effects of compression stockings to prevent muscular damage and to preserve muscular performance during a real half-ironman competition. We hypothesized that compression stockings would improve race time during the half-ironman race, lessen the indirect blood markers of muscle damage after the triathlon race and prevent muscle performance decline in those participants who wore them.

Methods

Subjects

Initially, 40 healthy and experienced triathletes were recruited by email or through internet announcements to participate in this study. Volunteers with a previous history of muscle disorder, cardiac or kidney disease or those taking medicines during the two prior weeks were discarded. Before enrolling in the investigation, a questionnaire about previous training, triathlon experience and best race time in half-ironman triathlon races was completed by each participant. Participants were matched (in pairs) for age, anthropometric data, training status and best race time in half-ironman. Afterwards, one participant of each pair was randomly assigned to the control group or to the compression stockings group. Four participants failed to complete the half-ironman triathlon race and their data were excluded from the study. Thus, this investigation presents data of 17 triathletes in the control group and 19 triathletes in the compression stocking group. Morphological variables, training status and best performance time in the half-ironman distance were similar between groups ($P > 0.05$; Table 1). Before enrolling in the investigation, all the participants were informed of the potential risks and discomforts associated with the experiments and signed their written consent to participate. The study was approved by the Camilo Jose Cela Ethics Committee in accordance with the latest version of the declaration of Helsinki.

Table 1 Morphological characteristics, training status and race time for triathletes that wore regular socks or compression stockings during a half-ironman triathlon race

	Control	Compression
n	17	19
Age (years)	35.8 ± 6.3	35.0 ± 5.3
Weight (kg)	73.2 ± 6.0	73.2 ± 5.2
Height (cm)	176 ± 5	176 ± 8
Experience (years)	4.4 ± 1.0	4.9 ± 1.1
Swimming training (km/week)	5.7 ± 2.3	6.2 ± 2.4
Cycling training (km/week)	173 ± 98	168 ± 88
Running training (km/week)	37.3 ± 13.6	33.1 ± 10.1
Best race time (min)	301 ± 25	303 ± 33

Swimming, cycling and running training represent the mean distance covered per week during the practices in the month prior to the race. The comparison between groups was always $P > 0.05$ for all the variables

Experimental protocol

Three hours before the onset of the race, participants arrived at an area close to the start line with no instructions about pre-exercise drinking and feeding. Participants were instructed to avoid pain-relieving strategies (e.g., analgesic medications, manual massage, ice, etc.) on the day before the race. Participants were blinded to the treatment during the pre-race measurements. On arrival, each participant was provided with an ingestible telemetry pill for the measurement of intestinal temperature (HT150002, HQ Inc, Palmetto, US) during the race. The pill was immediately ingested with 50 mL of tap water. Then, participants rested for 5 min in a recumbent chair and a 7-mL venous blood sample was drawn from an antecubital vein. Two milliliters of this blood sample was inserted into a tube with ethylenediaminetetraacetic acid (EDTA) while the remaining 5 mL was allowed to clot and centrifuged at 5,000*g* to obtain serum.

Participants then completed a standardized 10-min warm-up consisting of running, dynamic leg exercises and practice jumps. After that, participants performed two countermovement vertical jumps (CMJ) for maximal height on a force platform (Quattrojump, Kistler, Lausanne, Switzerland) to assess pre-race lower-limb power output. On command, the participant flexed their knees and jumped as high as possible while maintaining the hands on the waist and landed with both feet. All participants were previously familiarized with the jump test. The highest values for jump height, lower-limb power during the concentric phase of the jump and the second peak of ground reaction force during the landing (F2) were used for statistical analysis.

After that, participants were provided with a pair of compression stockings (Experimental group; Race and Recovery®, Compressport®, Paris, France) or ankle-length athletic socks (control group) according to the previous assignation. The compression stockings were made of knit fabrics (60 % polyamide, 25 % elastane and 15 % polyester) with a thickness of 0.1 mm and 59 mg/cm^2. The compression stocking covered from the malleolus to the apex of kneecap with graduated pressure (the highest pressure was at the malleolus and decreased proximally). The size of the compression stocking was assigned to the triathletes based on their lower leg maximal perimeter, according to the manufacturer's indications: <30–34.0 (size 1), 34.1–38.0 (size 2), 38.1–42.0 cm (size 3) and perimeters >42.1 cm (size 4). Participants were encouraged to put the compression stockings on prior to the start of the race (e.g., they also wore the compression stocking during the swimming section) and keep them on until the end of the race. The utilization of the compression stocking during the entire race was confirmed by visual observation by an investigator. The athletic socks were made of cotton, covered the foot up to ≈2 cm above the malleolus and applied minimal pressure on the lower leg. These socks were chosen for control purposes as the participants routinely wore this type of socks.

Just 15-min before the race (and after their habitual warm-up), participants were weighed in their competition clothes (±50 g scale; Radwag, Radom, Poland; prior to wearing the wetsuit) and intestinal temperature was measured using a wireless data recorder (HT150001, HQ Inc, Palmetto, USA). The race started at 12:00 hours and consisted of 1.9 km of swimming, 75 km of cycling (1,100 m net increase in altitude) and 21.1 km of running. At the start, the sky was clear and dry environment temperature was 24 °C. Mean ± SD (range) dry temperature during the event was 29 ± 3 °C (24–30 °C) with a relative humidity of 72.8 ± 8.0 % (65–85 %). The swim section was performed in a natural lake with water temperature at 19 ± 1 °C. All participants wore a neoprene wetsuit during the swim section. Participants drank and consumed food ad libitum and swam, cycled and ran at their own pace.

Within 1 min of the end of the race, participants went to a finish area and body mass and intestinal temperature were immediately measured using the same apparatus described previously. Participants were instructed to avoid drinking from the finish line till the post-race weighing and an experimenter ensured compliance. The body mass change attained during the race was calculated as percent reduction in body weight (pre-to post-race). After that, participants performed two countermovement vertical jumps, as previously described. Participants then rested for 5 min and a venous blood sample was obtained. The rating of perceived exertion after the race was assessed using the Borg scale (from 6 to 20 arbitrary units) while lower-limb muscle soreness [from 0 to 10 arbitrary units; (Ali et al. 2007)] was self-rated using a visual analog scale. After that, participants were provided with fluid (water and sports drinks) and finished their participation in the study.

Blood samples

A portion of each blood sample was introduced into a blood glucose analyzer (Accu-chek, Barcelona, Spain) to determine glucose concentration. The remaining blood was allowed to clot and serum was separated by centrifugation (10 min at 5,000*g*) and frozen at −80 °C until the day of analysis. At a later date, the serum portion was analyzed for osmolality (1,249, Advance 3MO, Barcelona, Spain), sodium, potassium, chloride (Nova 16, NovaBiomedical, Madrid, Spain) and calcium concentrations (BioSpectrometer, Eppendorf, Madrid, Spain). In addition, myoglobin, creatine kinase (CK) and lactate dehydrogenase (LDH) concentrations were measured as blood markers of muscle damage by means of an autoanalyzer (AU5400, Beckman Coulter, Indianapolis, USA).

Statistical analysis

The normality of each variable was initially tested with the Shapiro–Wilk test. For the variables obtained once during the experiment (race time, and self-rated fatigue and muscle soreness) the comparison between groups (compression stocking versus control group) was performed using Student's *t* test for independent samples. For the variables obtained twice during the experiment (body mass, body temperature, blood variables and jump variables) the comparison between groups was performed by using a two-way ANOVA (time × treatment). For each between-groups difference found in this study, we have calculated the effect size (ES). We considered ES ≈ 0.20 as small, ES ≈ 0.50 as moderate and ES > 0.80 as large, as proposed by Cohen (1992). We have not calculated ES for the pre-competition variables because they were obtained before wearing the compression stockings. The data were analyzed with the statistical package SPSS version 18.0 (SPSS Inc., Chicago, IL). The significance level was set at $P < 0.05$. Data are presented as mean ± standard deviation (SD).

Results

Triathlon race time and sector times

The mean time taken to complete the half-ironman triathlon was 315 ± 45 min for the group of triathletes that wore standard socks (control) and 310 ± 32 min for the group of triathletes that wore compression stockings ($P = 0.46$; ES = 0.11). These race times represented 104.7 ± 3.9 and 102.3 ± 3.0 % of the participants' best race time in half-ironman for the control and the compression stocking group, respectively ($P = 0.33$; ES = 0.62). There were no differences between groups in the velocities recorded for the swimming, cycling and running sectors and the effect size of wearing compression stockings was small in all sectors of the race (Table 2). In addition, the ratings of perceived exertion and lower-limb muscle soreness were similar between the control group and the group of triathletes with compression stockings (Table 2) while the effect sizes were small.

Body mass change and core body temperature

In the control group, body mass decreased from 73.2 ± 6.0 to 70.3 ± 6.3 kg ($P < 0.05$) representing a mean body mass change of −3.9 ± 1.6 %. In the compression stocking group, body mass decreased from 73.2 ± 5.2 to 70.1 ± 4.7 kg ($P < 0.05$) after the race and body mass

Table 2 Performance and changes in body mass and body temperature for triathletes that wore regular socks or compression stockings during a half-ironman triathlon race

Variable (units)	Control	Compression	*P* value	Effect size
Swimming velocity (m/s)	0.9 ± 0.1	0.9 ± 0.1	0.20	0.19
Cycling velocity (m/s)	8.3 ± 1.0	8.5 ± 1.7	0.15	0.21
Running velocity (m/s)	3.0 ± 0.5	3.0 ± 0.4	0.75	0.06
Pre-and post-race body mass (kg)				
Pre	73.2 ± 6.0	73.2 ± 5.2	0.95	–
Post	70.3 ± 6.3*	70.1 ± 4.7*	0.55	0.27
Body mass change (%)	−3.9 ± 1.6	−4.2 ± 1.1	0.02	0.18
Pre-and post-race body temperature (°C)				
Pre	37.7 ± 0.5	37.7 ± 0.7	0.95	–
Post	38.9 ± 0.6*	38.7 ± 0.7*	0.49	0.25
Body temperature change (°C)	1.2 ± 0.6	1.0 ± 0.7	0.52	0.25
Perceived exertion (arbitrary units)	17 ± 2	17 ± 2	0.58	0.17
Perceived muscle soreness (arbitrary units)	5.3 ± 2.1	6.0 ± 2.0	0.42	0.24

* Different from pre in the same group at $P < 0.05$

change was significantly higher than that in the control group (−4.2 ± 1.1 %; $P < 0.05$; Table 2). In the control group, body temperature before the race was 37.7 ± 0.5 °C and increased to 38.9 ± 0.6 °C at the end of the race ($P < 0.05$). Body temperature increased from 37.7 ± 0.7 to 38.7 ± 0.7 °C ($P < 0.05$) in the compression stocking group. The post-race body temperature ($P = 0.49$) and the increase in body temperature ($P = 0.52$) were similar between groups (Table 2). The effect size of wearing compression stockings in all these variables was small.

Blood and serum responses

Pre and post-race values for the blood and serum variables are shown in Table 3. Blood osmolality increased from 290.5 ± 2.1 to 299.0 ± 4.8 mOsm/kg ($P < 0.05$) during the race in the control group. In the compression stocking group, blood osmolality increased from 290.6 ± 3.1 mOsm/kg before the race to 303.1 ± 6.5 mOsm/kg after the race ($P < 0.05$). Post-race blood osmolality was significantly higher in the compression stocking group than in the control group (Table 3; $P < 0.05$) and the effect size was large. Serum glucose, sodium and calcium concentration significantly increased from pre-to-post race ($P < 0.05$) in both groups. However, serum chloride and potassium concentrations remained stable during the race. There were no differences between groups in the post-race values ($P > 0.05$) or in the magnitude of change from pre-to-post race in serum glucose, sodium, chloride, potassium and calcium concentrations ($P > 0.05$). In addition, the effect size of wearing compression stockings in these latter variables was always small (Table 3).

Blood markers for muscle damage

Serum myoglobin concentration increased from 30.2 ± 8.1 to 718 ± 119 µg/mL ($P < 0.05$) in the control group (Fig. 1). In the compression stocking group, serum myoglobin concentration increased from 35.5 ± 17.7 to 591 ± 100 µg/mL ($P < 0.05$) although this increase was not different from the one found in the control group ($P = 0.30$; ES = 0.35). The same pattern was present for the serum creatine kinase concentration; this variable increased from 158 ± 52 to 604 ± 137 U/L in the control group and from 180 ± 57 to 525 ± 69 U/L in the compression stocking group (Fig. 1; $P < 0.05$). There were no differences between groups in the post-race serum creatine kinase concentration ($P = 0.60$) or in the magnitude of change from pre-to-post race ($P = 0.41$; ES = 0.21). Nevertheless, the use of compression stockings produced moderate-to-high effect sizes for the reduction of post-exercise serum myoglobin (ES = 1.1) and CK concentrations (ES = 0.6). Serum LDH concentration increased from 326 ± 55 to 490 ± 88 U/L in the control group and from 310 ± 57 to 468 ± 69 U/L in the compression stocking group. The increase in LDH was not different between groups ($P = 0.67$; ES = 0.15).

Countermovement jump

Before the race, mean CMJ height was 29.3 ± 5.0 cm in the control group and 29.3 ± 5.6 cm in the compression stocking group. The compression stockings did not prevent the jump height reduction produced by the race (Table 4;

Table 3 Blood osmolality and serum electrolyte concentration in triathletes that wore regular socks or compression stockings during a half-ironman triathlon race

Variable (units)	Control	Compression	*P* value	Interaction	Effect size
Blood osmolality (mOsm/kg)					
Pre	290.5 ± 2.1	290.6 ± 3.1	0.63	0.08	–
Post	299.0 ± 4.8*	303.1 ± 6.5*	0.04		0.88
Glucose concentration (mM)					
Pre	117.3 ± 10.3	111.0 ± 10.2	0.10	0.88	–
Post	128.1 ± 17.4*	128.8 ± 17.2*	0.92		0.04
Sodium concentration (mM)					
Pre	140.7 ± 1.0	140.5 ± 1.0	0.56	0.24	–
Post	142.6 ± 2.4*	143.4 ± 1.6*	0.25		0.34
Chloride concentration (mM)					
Pre	102.7 ± 1.8	102.4 ± 1.3	0.46	0.45	–
Post	103.0 ± 3.3	103.5 ± 2.8	0.26		0.14
Potassium concentration (mM)					
Pre	4.5 ± 0.4	4.6 ± 0.4	0.38	0.32	–
Post	4.6 ± 0.4	4.6 ± 0.2	0.78		0.08
Calcium concentration (mM)					
Pre	9.5 ± 0.5	9.5 ± 0.4	0.82	0.92	–
Post	10.3 ± 0.5*	10.9 ± 0.5*	0.25		0.02

* Different from pre in the same group at $P < 0.05$

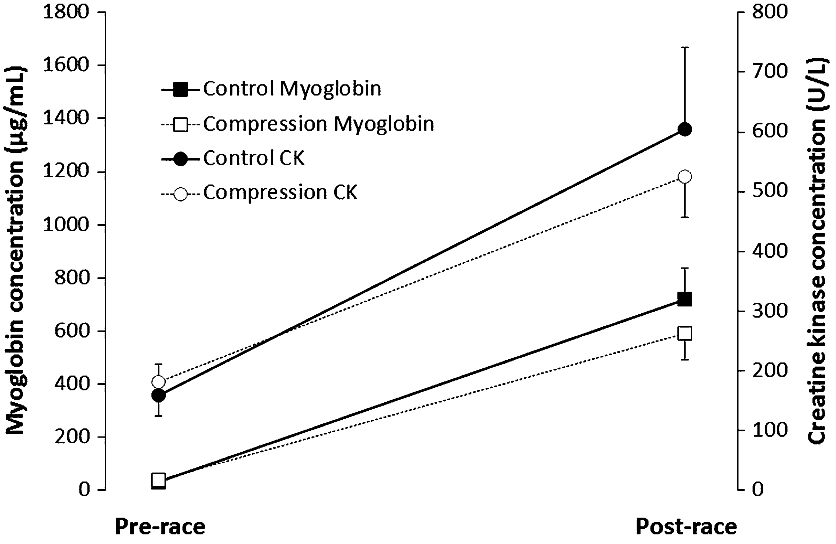

Fig. 1 Serum myoglobin and creatine kinase (CK) concentrations before and after a half-ironman triathlon race for triathletes that wore compression stockings (e.g., compression) or regular socks (e.g., control)

Table 4 Jump performance variables for triathletes that wore regular socks or compression stockings during a half-ironman triathlon race

Variable (units)	Control	Compression	*P* value	Effect size
Jump height (cm)				
Pre	29.3 ± 5.0	29.3 ± 5.6	0.98	–
Post	26.8 ± 4.8*	25.6 ± 4.7*	0.65	0.27
Jump height change (%)	−8.5 ± 3.0	−9.2 ± 5.3	0.47	0.17
Lower-limb muscle power (W/kg)				
Pre	24.7 ± 3.3	24.1 ± 4.2	0.65	–
Post	21.5 ± 3.4*	20.5 ± 5.8*	0.62	0.29
Lower-limb power change (%)	−13 ± 10	−15 ± 10	0.72	0.24
Pre-and post-race F2 (W/kg)				
Pre	5.9 ± 1.4	5.6 ± 1.7	0.56	–
Post	5.9 ± 1.3	5.8 ± 2.2	0.76	0.15
F2 change (%)	1.0 ± 5.0	3.5 ± 6.3	0.72	0.49

* Different from pre in the same group at $P < 0.05$

$P = 0.47$). Lower-limb power was also reduced in both groups after the race ($P < 0.05$) and the reduction was similar between groups (Table 4; $P = 0.72$). The second peak of ground force reaction (F2) did not change pre-to-post race in either the control or the compression groups. The effect size of wearing compression stockings was small for all the jump variables.

Discussion

The purpose of this study was to investigate the effectiveness of using compression stockings to prevent muscle damage and thus to improve muscle function and time performance during a half-ironman race. For this purpose, performance and physiological variables measured in a group of experienced triathletes that wore graduated compression stockings were compared with those of a control group (wearing regular athletic socks). The main outcomes were the use of compression stockings did not improve total race time or the velocities in the swimming, cycling and running sectors of the triathlon (Table 2). In addition, the triathletes wearing compression stockings presented similar post-race reductions in jump height and maximal lower-limb muscle power output, and they had comparable blood myoglobin and CK concentrations (Fig. 1) with the control group. All these data suggest that the use of compression stockings is not effective to increase race performance or to prevent the deterioration of muscle function during a half-ironman triathlon.

Compression garments were originally conceived to improve venous return in patients with chronic venous insufficiency (Agnelli 2004). In these patients, compression garments have been effective to improve venous hemodynamics (Ibegbuna et al. 2003) and muscle oxygenation during walking (Agu et al. 2004). In healthy women, the use of compression garments reduced the formation of edema and minimized the amount of lower body venous pooling after a standing fatigue protocol (Kraemer et al. 2000). On the contrary, the results about the effectiveness of compression garments to improve exercise performance are inconsistent. The outcomes of wearing compression clothing in the sport setting are uneven due to the variability in the type, duration and intensity of the exercise protocols, the procedures used to assess exercise performance, the training status of participants, the type of garment used/body area covered and the applied pressures (MacRae et al. 2011; Sperlich et al. 2011).

In experienced runners, the use of compression garments reduced energy cost and the VO_2 slow component during prolonged running (Bringard et al. 2006) and increased time to exhaustion during a maximal running test (Kemmler et al. 2009). However, compression garments were ineffective to increase single (Doan et al. 2003) or repeated sprint performance (Ali et al. 2007; Duffield and Portus 2007), long-distance running performance (Ali et al. 2007; Dascombe et al. 2011; Vercruyssen et al. 2012) and cycling endurance performance (Burden and Glaister 2012; MacRae et al. 2012). A recent review (Born et al. 2013) indicates that compression clothing might assist athletic performance in certain sport situations but the magnitude of this effect is minor in most cases while the practical relevance of the benefits for overall performance is marginal. In the present investigation, the use of compression stockings did not affect the velocity in the different sectors of the race (swimming, cycling and running; Table 2) and did not improve total race time. In addition, the effect size of wearing compression stockings on swimming, cycling and running velocities was small. Thus, wearing compression stockings was not effective for increasing race performance during a half-ironman triathlon, as previously found in other exercise protocols.

The use of compression garments might also be effective to improve performance by reducing muscle vibrations during muscle contractions (Kraemer et al. 1998) which in turn might lessen the muscle damage produced during exercising (MacRae et al. 2011). Compression garments have been effective in improving recovery of muscle function and ameliorating muscle soreness after several protocols of exercise-induced muscle damage (Jakeman et al. 2010a, b; Kraemer et al. 2001). In contrast, compression stockings did not change muscle soreness after maximal running (Ali et al. 2010) or blood markers of muscle damage after repeated squats (French et al. 2008). To our knowledge, this is the first study that has investigated the effect of compression stockings during a real sport competition. In the present investigation, the triathletes that wore regular athletic socks reduced their maximal jump height by 8.5 ± 3.0 % and lower limb muscle power output by 13 ± 10 % in comparison with pre-race values (Table 4), as has been found previously (Del Coso et al. 2012a; Margaritis et al. 1999). Interestingly, maximal jump height reduction (9.2 ± 5.3 %) and lower limb muscle power reduction (15 ± 10 %) after the race were similar for the compression stocking group suggesting that compression stockings did not ameliorate the loss of muscle performance produced by a triathlon.

Exercise-induced muscle damage is accompanied by severe damage in the sarcolemma, T-tubules and myofibrils, resulting in the release of muscle proteins (mainly myoglobin and CK) into the blood stream (Schiff et al. 1978). These blood markers are typically used to determine the presence of muscle damage although they are unspecific of the zone damaged and their concentrations are not considered a good indicator of the magnitude of the muscle damage (Clarkson and Sayers 1999). The use of compression garments has been found effective for reducing muscle soreness (Jakeman et al. 2010a, b), swelling (Kraemer et al. 2001) and blood concentrations of myoglobin and CK when the garments were worn following exercise (Kraemer et al. 2010). However, the use of lower-body compression garments during the course of exercise did not modify the concentration of blood CK after exercise-induced muscle damage (Duffield et al. 2010, 2008). In the present investigation, the group with compression stockings tended to have lower post-race blood myoglobin and CK concentrations than the control group and the effect sizes were moderate-to-high in these variables. Nevertheless, the between-groups differences in post-race blood myoglobin and CK concentrations did not reach statistical significance (Fig. 1). The high inter-individual variability present in the concentrations of both myoglobin and CK concentrations after exercise likely barred obtaining significant differences when comparing groups. Furthermore, there were no differences between groups in the perceived muscle soreness after the race (Table 1). The causes for exercise-induced muscle damage in endurance events can be either mechanical or metabolic in nature (Tee et al. 2007) while the use of compression garments during a triathlon mainly focuses on the mechanistic prevention of this phenomenon. All these data indicate that wearing compression stocking did not represent any advantage for maintaining muscle function during a triathlon event.

A body water deficit of above 2 % has been repeatedly related to reduced performance during endurance events (Sawka et al. 2007) and has been proposed as one of the main factors responsible for fatigue during triathlon events (Jeukendrup et al. 2005). In the present study, mean body mass reduction in the control group surpassed that threshold (Table 2) in part because a portion of the body mass reduction during long-distance triathlons corresponds to the loss of fat mass (Knechtle et al. 2010). Surprisingly, the body mass reduction in the group of triathletes that wore compression stockings was significantly higher than that in the control group, although the size effect was small (Table 2; $P < 0.05$). This augmented body mass decrease was related to a higher body water deficit because post-race blood osmolality was also higher in the compression stocking group (Table 3; $P < 0.05$). These effects may be related to the increased skin temperature recorded when wearing compression garments (Houghton et al. 2009) or due to reduced water intake during the race, because participants in this investigation drank ad libitum during the race. However, the slightly higher body water deficit found in the compression stocking group was not accompanied by higher perceived fatigue or augmented core body temperature, as previously found (MacRae et al. 2012). The use of compression stockings minimally increased the body water deficit during the race but without appreciable physiological consequences.

The approach of this investigation was ecological and the outcomes of two different groups of subjects were compared in a real competition without standardizing carbohydrate and beverage intake during the race. Although there were no differences in post-exercise blood glucose concentration, the two groups slightly differed in body mass change and blood osmolality after the race. However, our data indicate that the slightly higher water deficit found in the compression stocking group minimally affected the outcomes of the investigation, as previously mentioned. Another limitation of this experimental design is the lack of follow-up during the recovery process after the half-ironman race. The origin of the participants hindered the obtaining of blood samples and muscle performance measurements in the subsequent days after the triathlon race. Compression garments might enhance the recovery of muscle strength and power and lessen the concentrations of creatine kinase after exercise-induced muscle damage (Hill et al. 2013). However, with our experimental design, it is not possible to determine the effects of wearing compression stockings on the recovery phase of a half-ironman competition.

Conclusions

In summary, wearing compression stockings did not improve race performance and did not prevent the reduction in lower-limb muscle function during a half-iroman triathlon. Furthermore, the use of compression stockings did not reduce post-race blood concentrations of myoglobin and creatine kinase suggesting that this strategy did not preclude muscle fiber damage during the competition. Thus, compression stockings were ineffective for averting muscle fatigue and muscle damage during triathlon events.

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Conflict of interest The authors declare that they have no conflict of interest derived from the outcomes of this study.

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