Custom fitted compression garments enhance recovery from muscle damage in rugby players

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ABSTRACT

PURPOSE*:* To evaluate the effects of custom fitted compression garments (CG) on recovery from muscle damage in rugby players. **METHODS:** Forty-five players were tested for lower body strength, power, and indices of muscle-damage before completing a damaging protocol (20 x 20 m sprints with 5 m deceleration, 100 drop-jumps). Players were randomly assigned to wear either custom fitted (CF, n = 13), or standard sized CG (SSG, n = 16), or to received sham ultrasound therapy (CON, n = 16) immediately post-exercise. Players were re-tested immediately, then after 24 h and 48 h. **RESULTS:** Strength recovery was significantly different between groups (F = 2.7, p = 0.02), with only CF recovering to baseline values by 48 h (p = 0.973). Time x condition effects were also apparent for creatine kinase activity (χ^2 = 30.4, p < 0.001) and mid-thigh girth (F = 3.7, p = 0.005), with faster recovery apparent in CF compared to both CON and SSG (p < 0.05). **CONCLUSIONS:** Custom fitted CG improved strength recovery and indices of muscle damage in rugby players, compared to controls and standard sized garments. **PRACTICAL APPLICATIONS:** Athletes and coaches would be advised to use appropriately fitted CG to enhance strength recovery following damaging exercise.

Key Words: recovery, strength, athlete, muscle damage

INTRODUCTION

Rugby Union is a contact sport played over 80 minutes, for which high levels of strength, power and speed are required for optimal performance (6). However, rugby match-play typically incurs exercise induced muscle damage (EIMD), which may lead to delayed onset muscle soreness (DOMS) and impaired muscular function (2, 23, 43). Furthermore, while rugby players frequently use resistance training to increase levels of lean mass, strength and power (43, 45), such training modalities induce EIMD and may impair performance for several days (43, 45). Whilst insufficient recovery before matches has been highlighted as a major risk factor for injury (2), studies commonly report that players compete while still suffering from EIMD (2, 23). Furthermore, recent findings have reported that the magnitude of pre-match EIMD was significantly negatively correlated with both running distance and coach perceptions of match performance (22). Importantly, as strength and power adaptations depend upon training intensity (37), reduced physical capacity following EIMD also has the potential to impede improvements from training.

The search for effective recovery methods in rugby has led to the adoption of numerous strategies (14), including the use of compression garments (CG). To date, evidence suggests that CG are effective for ameliorating the symptoms of EIMD in rugby players, including soreness (10, 11, 42) and structural damage (14, 42). Compression has also been shown to enhance the recovery of strength and power following EIMD in athletic populations (4, 15, 33), as well as next-day endurance-performance following high intensity exercise (9). However, the benefits of CG for functional recovery in rugby players are equivocal, with insignificant effects being reported for both the recovery of lower body strength following plyometric exercise (10) and power recovery following simulated match-play (11).

Inconsistent results on CG to date may be related to variation in the pressures applied between trials. For example, while clinical recommendations on CG advocate pressures of at least 18 mmHg to be applied below the knee (34), pressures used in recovery trials are frequently lower (4, 9, 36). Where pressures have been reported, many studies have obtained values from indirect modelling techniques (25) or those predicted by manufacturers (4, 10). Furthermore, anthropometric variation between athletes has been shown to result in non-uniform pressures, even when standard sized garments are fitted according to stature and body-mass (19). As a result, many athletes using CG may receive pressures far below those required for haemodynamic improvements (30, 34). This may affect recovery, as observations that CG improve soreness and mobility following EIMD are frequently reported alongside reductions in limb circumference, taken as a measure of local inflammation (4, 24, 26). As the reduction of oedema involves “shunting” blood from peripheral vessels to enhance venous return (34), suboptimal pressures may therefore be ineffective for recovery. Other potential mechanisms by which CG may work also rely upon improved circulation, such as enhanced metabolite removal (39) and nutrient delivery (27). The aim of the current study was therefore to evaluate the effects of CG applying different pressures on muscular recovery following EIMD in rugby players.

METHODS

Experimental approach to the problem

The primary research question addressed in the present study was whether custom fitted CG (CF) enhanced recovery from damaging exercise in comparison to standard sized garments (SSG) or a sham treatment (CON). Accordingly, the effects of CG on recovery from EIMD were evaluated using a split-plot design to assess between-group (x 3) differences in recovery markers over time (x 4).

Subjects

Ethical approval was provided by St Mary’s University ethics committee in accordance with the Declaration of Helsinki. Rugby players over the age of 18 were subsequently recruited from the university and local teams, with a maximum age limit of 40 years. Participants were block-randomized into three groups by a third party, being allocated either to CF, SSG (2XU, MA1551b men’s compression tights, Melbourne, Australia) or CON. The use of parallel groups was chosen to avoid the confounding influence of the “repeated bout effect”, whereby as little as a single session of damaging exercise may rapidly incur protective adaptations which reduce EIMD from further bouts (21). Inclusion criteria required participants to be actively playing, with a minimum of 2 years training experience. Players were excluded if they presented any injuries that had prevented normal training over the month before testing, or suffered from chronic conditions that could have affected their ability to safely perform muscle damaging exercise. Athletes were requested to avoid strenuous exercise for 48 h before the start of the study, and refrain from exercise throughout 48 h recovery. A sample size of n = 16 was calculated using effect sizes from previous trials (17, 24), selecting an alpha value of 0.05 with 80 % statistical power.

Procedures

Baseline measures

Participants were assessed for anthropometry by a level 1 anthropometrist (Table 1) in accordance with guidelines set by the International Society of Anthropometry and Kinanthropometry (ISAK). Soreness (200 mm visual analogue scale) was also assessed, while mid-thigh girth (MTG) was taken as a measure of swelling (spring loaded tape measure - Lafayette Instrument Co, Lafayette, Ind., USA). Muscle damage was further quantified from plasma creatine kinase activity (CK). A 4 ml blood sample was drawn from a branch of the antecubital vein into a chilled EDTA vacutainer, before spinning the sample at 4°C at 2500 rpm for 20 min (16). Plasma was aliquoted and immediately frozen at −80°C before analysis using an automated analyser (RX Daytona, Randox, County Antrim, Northern Ireland). A standardized warm up of 5 min cycling at 100 W was then completed by each player (Monark Ergomedic 874E, Vansbro, Sweden) before undergoing familiarization with each performance test (three repetitions). Subsequently, lower-body strength was assessed with a strain gauge by measuring the best of three attempts of maximal isometric knee extension (MIE Medical Research Ltd., Leeds, UK). Participants were seated on a plyometric box and positioned with a knee angle of 90^{o} as measured with a goniometer (41). Subsequently, countermovement jump performance was measured using a force plate (Type 9281E, Kistler, Winterthur, Switzerland). Participants were requested to jump with their hands on their hips while no specific advice was given concerning the depth of the countermovement. Finally, 30 m sprint time was measured with electronic timing gates (Brower, Utah, USA). All performance measures were taken as the best from of three attempts by the same researcher, with verbal encouragement provided. Repetitions were separated by a minimum of 1 min.

Eccentric muscle damage protocol

Participants then completed 20 sets of 20 m sprints with a 5 m deceleration, followed by 100 drop jumps. Sprints were completed one per minute on a rolling clock in a similar procedure to an existing muscle damage protocol using team-sport athletes (29), and were timed to provide real-time feedback and encourage maximal effort. Drop jumps were then performed from a 0.6 m platform to ensure EIMD (18), with athletes encouraged to jump as high as possible after an eccentric phase which resulted in both thighs dropping parallel with the floor.

Compression garments

Participants were requested to wear their allocated garments immediately post-exercise for 48 h recovery, being removed only to wash and for subsequent testing. Participants in CON received 5 min sham ultrasound on each of the thighs, calves and hamstrings (17). Custom fitted garments were designed to apply pressures of 30-35 mmHg at the ankle, graduating to 20 mmHg at the thigh, after taking 3D scans of participants' legs using the manufacturers' proprietary method (Isobar Compression, Manchester, UK). Participants in SSG were fitted for garments according to stature and body mass in line with manufacturer guidelines. Pressures at the skin-garment interface were measured in a standing position immediately above the medial malleolus, and at the medial calf and mid-thigh skinfold sites, using a pressure monitor validated previously (Kikuhime pressure Measuring System, Harada Corp, Osaka, Japan)(3).

Assessment of recovery

Recovery was quantified by repeating the initial assessment immediately post-exercise, then at 24 h and 48 h (Figure 1). Assessment of blinding procedures was carried out by asking participants to rate their treatment out of 10 for perceived effectiveness (to the nearest 0.5) following the final test.

Figure 1

Statistical Analysis

All statistical analyses were carried out using an open-access statistical software package (R Foundation for Statistical Computing, Vienna, Austria). Residual values were visually assessed for normality with QQ-plots and histograms, before quantitative assessment using the Shapiro-Wilk test. Normally distributed data were assessed for between-group differences in performance and physiological factors over time using a 2-way, time x condition (4 x 3) mixed-measures ANOVA. Data were assessed for homogeneity of variance between groups, and the Greenhouse-Geisser correction employed where heterogeneity occurred. Where residuals were not normally distributed, data were compared to alternative distributions (8). Ordinal data were assessed with a non-parametric alternative to the split-plot ANOVA (13, 28). Where significant time x condition interactions were found, post hoc pairwise analyses were conducted between groups and between time-points with the ‘emmeans’ and ‘nparcomp’ packages, adjusting for multiple comparisons (13, 28, 32). Changes in performance were presented as normalized scores (% baseline) while statistics were run on raw values. Effect sizes (ES) were calculated as Cohen’s d, and reported alongside 90 % confidence intervals (CI) as (ES [LCL, UCL]), where LCL and UCL represent the lower and upper 90 % confidence limits. A 1-way ANOVA was used to assess differences in measured pressures between garments and perceived efficacy between conditions. The threshold values for standardized changes were as follows: ≤ 0.2 (trivial), 0.2 - 0.49 (small), 0.5 – 0.79 (moderate), > 0.8 (large), where 0.2 was taken to represent the smallest worthwhile effect (1). Effects were deemed unclear if the 90 % CI transected the threshold for a trivial effect (1). Reliability was assessed by assessing the consistency of measured muscle damage responses with the intraclass correlation coefficient (ICC), being classed as “moderate”, “good”, or “excellent” if values fell between 0.4-0.59, 0.6 - 0.74 and 0.75 – 1 respectively (20, 40). Significance was set at $p \leq 0.05$.

RESULTS

Participant Characteristics

Three players were excluded after initial recruitment due to subsequent injuries, resulting in CF containing only 13 players (Table 1). There were no between-group differences for baseline measurements of anthropometry, performance or muscle damage, including body mass ($p = 0.126$), skinfold thickness ($p = 0.250$), lower body strength ($p = 0.201$), sprint performance ($p = 0.638$), MTG ($p = 0.115$) or countermovement jump force ($p = 0.066$). Assessment of blinding procedures was shown to be adequate as there were no significant differences in ratings of perceived efficacy between the CF (6/10), SSG (5/10) and CON (5/10) conditions ($F = 2.1$, $p = 0.139$). Residuals for CK and sprint time were skewed, and therefore were assessed by fitting values to a gamma distribution. Such distribution functions allow flexibility and specificity when fitting models to skewed data (8). Normally distributed data for strength, peak countermovement jump force and MTG were analysed directly with parametric statistics.

****Table 1****

Garment pressures

Garment pressures were all significantly higher in CF compared to SSG (Table 1), including at the ankle (t = 15.6, $p < 0.001$, ES = 1.86 [1.13, 2.60]), calf (t = 10.8, $p < 0.001$, ES = 1.79 [1.06, 2.51]) and thigh (t = 11.1, $p < 0.001$, ES = 1.79 [1.06, 2.51]).

Performance

Measures of strength, countermovement jump performance and 30 m sprint time all demonstrated excellent reliability (0.80, 0.90 and 0.86 respectively), with no evidence of familiarization throughout testing (Figures 2 – 3, Tables 2 -3). Analysis of variance revealed that strength performance declined significantly over time (F = 41.6, $p < 0.001$), with mean values following EIMD falling to 83.7 ± 9.0 % baseline post-exercise, 90.4 ± 9.4 % at 24 h, and 93.1 ± 10.0 % at 48 h. Strength recovery differed between conditions as shown by a significant time x condition interaction (F = 2.7, $p = 0.02$; Figure 2), although adjusted post hoc pairwise comparisons were not significant ($p > 0.05$). Large, clear improvements in strength were observed in CF compared to CON at all time-points, with a large, clear benefit from CF also apparent compared to SSG at 48 h (Table 4). Descriptive differences between SSG and CON were characterised by unclear effects at all time-points (Table 4). Strength in CF was not significantly different to baseline at either 24 h ($p = 0.328$) or 48 h ($p = 0.973$), recovering to 95.8 ± 9.5 % and 99.8 ± 10.4 % respectively (Figure 2). However, strength was still significantly impaired at 24 h in both SSG and CON (89.9 ± 6.5 %, $p < 0.001$; 86.5 ± 10.1 %, $p < 0.001$, respectively), remaining below baseline values at 48 h in both groups (90.1 ± 8.8 %, $p < 0.001$; 90.7 ± 8.6, $p < 0.001$ - Figure 2). Peak counter-movement jump force (Table 2, Table 3) also varied with time after the muscle damage protocol (F = 5.3, $p = 0.003$), but was not subject to a time x group interaction (F = 0.6, $p = 0.71$). Unclear trivial and small effects were observed between CF and CON at all time-points, as well as between CF and SSG, and between SSG and CON (Table 4). Sprint time increased significantly following exercise ($\chi^2 = 31.9$, $p < 0.001$) deteriorating to 104.7 ± 3.7 % baseline post-exercise, 103.1 ± 4.1 % at 24 h and 103.3 ± 3.8 % at 48 h ($p < 0.05$). While sprint time was not subject to a significant time x condition interaction ($\chi^2 = 4.5$, $p = 0.61$), large clear beneficial effects were apparent between CF and CON at both post-exercise and 48 h time-points (Table 4). Unclear small and moderate effects existed between CF and SSG, and between SSG and CON (Table 4).

****Figure 2****

Table 2

Table 3

Indices of muscle damage

Measures of CK activity and MTG demonstrated good and excellent reliability (0.65 and 0.99 respectively), while soreness demonstrated only moderate reliability (0.45). Mid-thigh girth (Figure 4) varied significantly over time following muscle damage (F = 14.8, $p < 0.001$), and was subject to a significant time x group interaction (F = 3.7, $p = 0.005$). Adjusted pairwise comparisons revealed a significant time x group interaction between CF and CON only ($p = 0.002$), while analyses of individual groups confirmed that MTG remained unchanged in CF at post-exercise (100.1 ± 0.7 %, $p = 0.975$), 24 h (99.8 ± 0.8 %, $p = 0.809$) and 48 h time-points (100.0 ± 1.3 %, $p = 0.943$). In contrast, both SSG and CON displayed increased MTG at both 24 h (100.7 ± 0.9 % $p = 0.016$; 100.9 ± 1.4 % $p = 0.003$ respectively) and 48 h time-points (101.0 ± 1.2 %, $p < 0.001$; 101.5 ± 0.9 %, $p < 0.001$). Large clear improvements in MTG were apparent between CF and CON at 24 h and 48 h, with a large clear beneficial effect also observed between CF and SSG at 24 h (Table 4). The effects of SSG compared to CON were unclear (Table 4).

Both soreness ($\chi^2 = 43.5$, $p < 0.001$ – Figure 4) and CK ($\chi^2 = 313$, $p < 0.001$) increased significantly following exercise, with mean CK activity varying from 175.8 ± 100.7 % baseline values at the post-exercise time-point to 559.3 ± 554.6 % and 380.5 ± 319.9 % at 24 h and 48 h, respectively (Figure 3). Changes in soreness throughout recovery did not differ between groups ($\chi^2 = 0.3$, $p = 0.864$), while the effects of CF were unclear compared to SSG and CON at all time-points (Table 4). In contrast, CK was subject to a significant time x group interaction ($\chi^2 = 30.4$, $p < 0.001$). Adjusted pairwise comparisons demonstrated significant time x group interactions between CF and CON ($p < 0.001$) and between CF and SSG ($p = 0.03$), while the difference between SSG and CON failed to reach significance ($p = 0.199$). Whilst levels of CK in SSG and CON were significantly greater than baseline at all time-points throughout recovery ($p < 0.001$), CK had recovered by 48 h in CF ($p = 0.067$). The effects of CF compared to SSG and CON were unclear for at all time-points (Table 4).

Table 4

Figure 3

Figure 4

DISCUSSION

The results of the current study demonstrate that custom fitted CG designed to apply higher pressures than commercially available garments were associated with improved strength recovery following EIMD in rugby players. This is the first study to demonstrate improved functional recovery from custom-fitted CG compared to standard-sized garments. These results add to a large body of evidence which indicates that CG are effective for ameliorating strength deficits from EIMD, with greater levels of isometric strength consistently reported alongside improvements in mobility, soreness and structural damage (4, 24, 26). In the present study, lower body strength in CF was 9.4 % greater than CON at 24 h, and 9.1 % greater at 48 h. Such findings are likely to translate into improved rugby performance, with higher levels of strength being associated with greater tackling ability (38) and sprint speed (6). However, although EIMD in rugby players impairs strength and competitive performance for several days (10, 11, 22, 23), players frequently compete before they have fully recovered (2, 23). Custom fitted CG enhance strength recovery in rugby players, which is likely to benefit competitive performance.

The finding that only higher pressure garments enhanced recovery agrees with recently published work on recreational athletes from our laboratory (18). Hill et al., (2017) reported that improvements in lower body strength and power were greater when garments which applied (directly measured) pressures of 14.8 ± 2.2 mmHg at the thigh and 24.3 ± 3.7 mmHg at the calf were worn, in comparison to lower pressures (8.1 ± 1.3 mmHg and 14.8 ± 2.1 mmHg, respectively). Such pressures are comparable to those from the current study (24 ± 4 mmHg at the calf, 19 ± 3 mmHg at the thigh). Conversely, instances where CG have been ineffective for recovery in rugby players may be explained by standard sized garments applying insufficient pressures (10, 11). Duffield et al. (10) demonstrated no benefit from CG on the recovery of maximal knee extension in the 24 h following 10 sets of 20-m sprints and 100 plyometric bounds, while the same group also found no effect on the recovery of peak scrummaging power throughout 72 h recovery after a simulated match (11). However, pressure was not directly measured in either trial. Where reported (10), an estimated pressure of 10 mmHg at the thigh was based solely on based on manufacturer guidelines. Regardless of accuracy, such levels may be below those required for venous return, estimated as 17.3 and 15.1 mmHg at the thigh and calf respectively (44). As the benefits of CG are thought to be mediated by haemodynamic improvements (27, 34, 39), it is therefore unlikely that CG which apply lower pressures will be effective. Considering the large stature, limb girths and body mass of rugby players (12), the large variation in anthropometry between-positions (12), and inconsistencies in the fit of standard sized garments (19), it is impossible to know if these players were receiving adequate compression pressures.

Improved strength recovery in CF was observed alongside significant reductions in both MTG and in CK. These findings are consistent with evidence suggesting that the benefits of compression are associated with an ameliorative effect on EIMD (4, 15, 24, 25). In support of this theory, the magnitude of EIMD observed in the current study was similar to that from previous trials where CG have been shown to be effective (10, 11). The 16.2 % force decrement observed in the current study occurred alongside CK elevations exceeding 800 % baseline values (1351 IU), representing similar levels of damage to other studies in which CG have improved strength and power recovery (24, 25). Conversely, null findings from CG in rugby players have been reported following less damaging exercise (10, 11). While the current trial demonstrated no effects of CG on soreness, this measure is highly variable between participants and frequently demonstrates only limited reliability (35, 42). Soreness in the present study was still 34.2 % and 29.3 % higher in CON compared to CF at 24 h and 48 h respectively, although these differences failed to reach significance. In the current trial, CF CG were shown to enhance strength recovery following damaging exercise and were associated with improved recovery from EIMD.

In contrast to muscular strength, CG failed to improve either the recovery of 30 m sprint performance or peak counter-movement jump force. However, whilst a reduction in isometric strength is a defining characteristic of EIMD, jumping and sprint performance are also influenced by coordination, technique (7) and the stretch-shortening cycle (5). Accordingly, any therapeutic effects of CG on muscle damage may not have been detected with such complex performance outcomes. In support of this idea, Byrne & Eston (5) have reported that countermovement jump performance may be better maintained following EIMD in comparison to both the squat-jump and isometric strength (5). Furthermore, although the effects of compression on sprint performance were not significant, a large, clear 4.4 % improvement in CF was observed at 48 h (Table 2). It is possible that the substantial variation observed in intra-participant training status, and resulting heterogeneity in muscle damage responses, obscured a worthwhile change. Players ranged from sub-elite to recreational athletes, with reductions in isometric strength ranging from -38.2 to -5.2 % and changes in sprint time varying between a 13.2 % deterioration to a 1.0 % improvement in one player. Additionally, despite displaying excellent ICC values in the present study, sprint performance typically exhibits a great deal of variation between rugby players (7). As greater standard error values can obscure worthwhile effects in small samples (31) the use of such a varied cohort (ranging from recreational to sub-elite players) represents a limitation to this study. More research is required into the effects of CG on sprint recovery in a larger and more homogenous sample.

The use of custom fitted CG was associated with a significant improvement in the recovery of lower body strength following damaging exercise. Average pressures in CF were significantly greater than those applied by SSG, reaching levels likely to improve venous return. Functional improvements in CF were significantly greater than those from either a sham treatment or the use of SSG, and represented meaningful improvements for rugby players. Such benefits were observed alongside lower MTG values and reduced muscular trauma, suggesting an ameliorative effect on the symptoms of EIMD.

PRACTICAL APPLICATIONS

The current findings add to recent results which suggest that high-pressure CG may enhance recovery from EIMD compared to commercially available garments providing lower pressures (18). Accordingly, athletes seeking to maintain muscular strength following damaging exercise would be advised to use CF garments to aid recovery, or to assess the pressures exerted by chosen CG to inform their choices. As rugby players frequently compete while still displaying symptoms of EIMD (2, 23), the use of custom fitted CG could help optimise recovery before competition. Furthermore, the use of CG may enhance recovery to allow players to maximise strength and power performance throughout training. More research is required to quantify the effects of CG on recovery prior to match-play, and to assess the impact of CG on adaptive responses.

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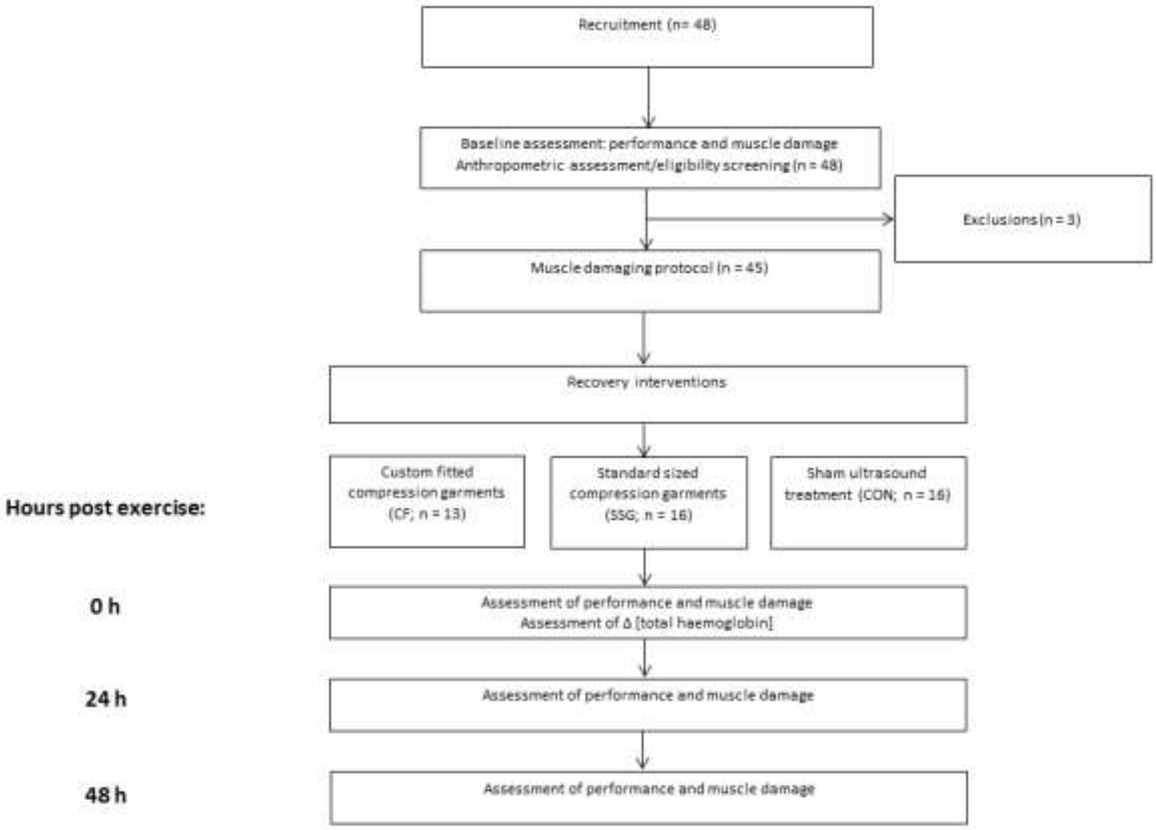

Figure 1. Study design

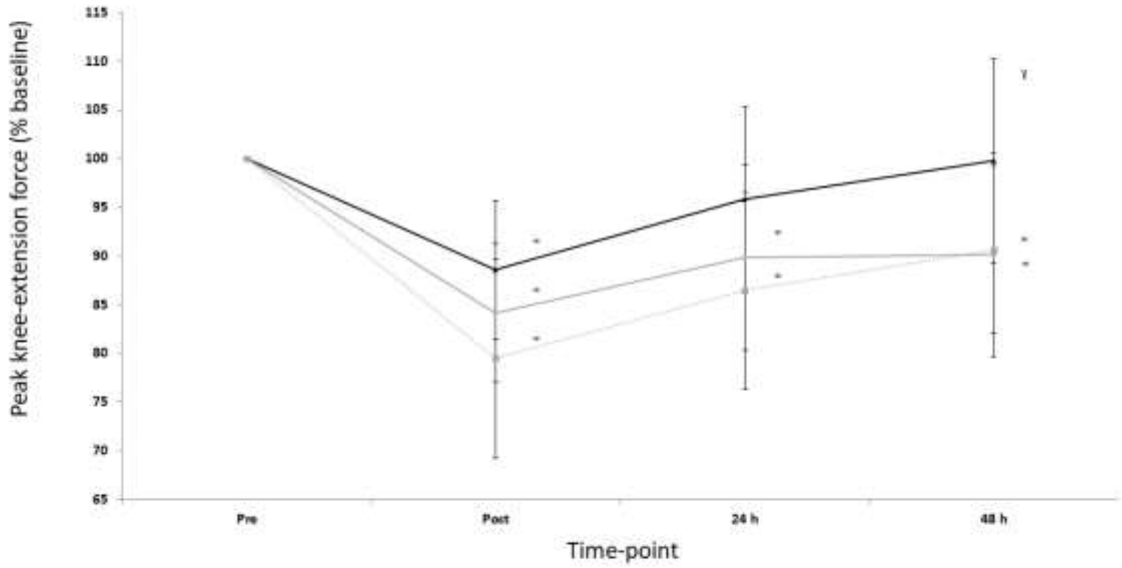

Figure 2. Recovery of lower-body strength performance over 48 h recovery

Black solid line = custom fitted garments; Grey solid line = standard sized garments; Grey dashed line = control. ɣ = significant time x group effect (*p* < 0.05). * = significant group difference from baseline values (*p* < 0.05)

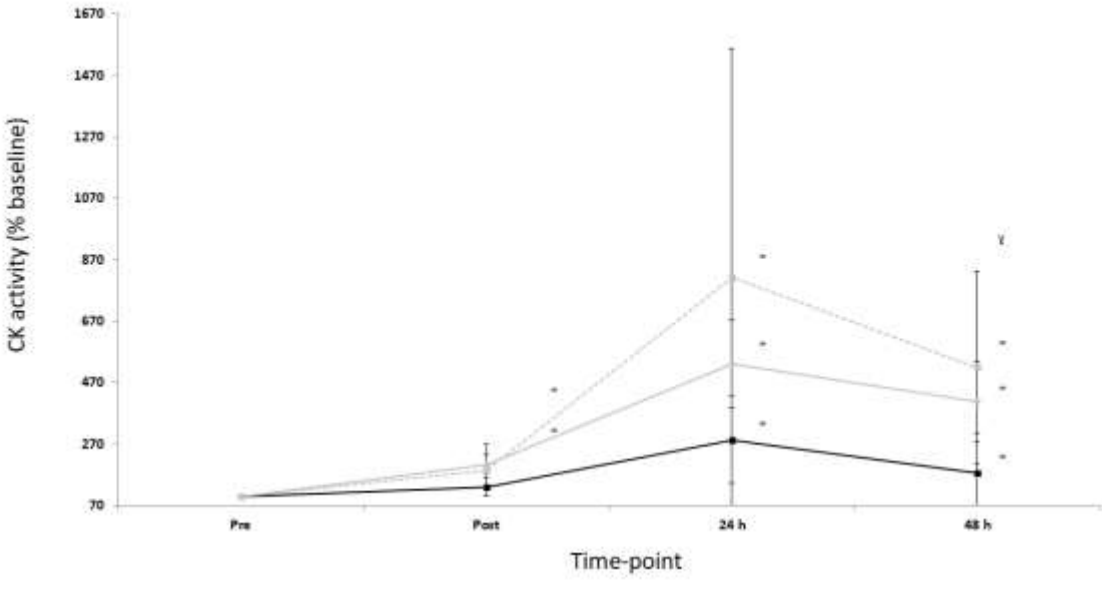

Figure 3. Mean creatine kinase activity as % baseline over 48 h recovery

Black solid line = custom fitted garments; Grey solid line = standard sized garments; Grey dashed line = control. ɣ = significant time x group effect (*p* < 0.05). * = significant group difference from baseline values (*p* < 0.05)

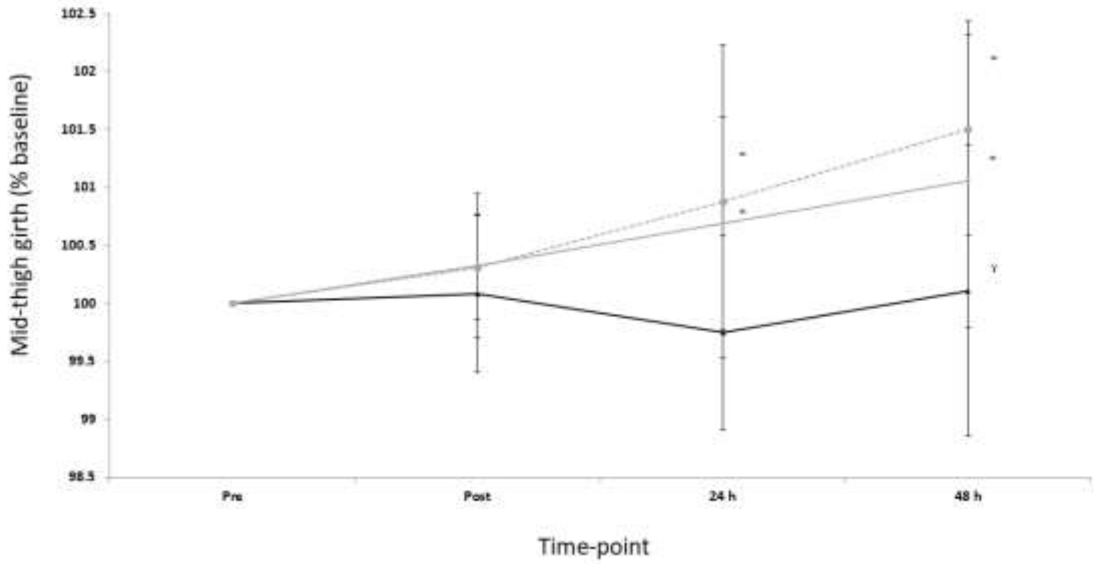

Figure 4. Mean mid-thigh girth as % baseline over 48 h recovery

Black solid line = custom fitted garments; Grey solid line = standard sized garments; Grey dashed line = control. ɣ = significant time x group effect ($p < 0.05$); * = significant group difference from baseline values ($p < 0.05$)

Table 1. Participant Characteristics

CF = custom fitted garments; SSG = standard sized garments; CON = control MTG = Mid-thigh girth; CMJFpk = peak counter-movement jump force; * = significant difference from SSG

Group	CF (n = 13)	SSG (n = 16)	CON (n = 16)
Age (y)	24 ± 6	23 ± 3	22 ± 4
Stature (m)	1.80 ± 0.08	1.83 ± 0.07	1.79 ± 0.09
Body mass (kg)	86.1 ± 15.9	97.3 ± 14.1	92.3 ± 13.5
Skinfolds Σ8 (mm)	99.2 ± 44.9	124.8 ± 48.5	107.5 ± 44.4
Strength (N)	511 ± 122	582 ± 93	589 ± 121
30 m Sprint (s)	4.45 ± 0.43	4.58 ± 0.34	4.52 ± 0.30
MTG (cm)	61.1 ± 5.4	65.1 ± 4.6	62.5 ± 5.5
$CMJF_{pk}$ (N)	1931 ± 401	2279 ± 372	2047 ± 421
Garment pressure, ankle (mmHg)	32 ± 3 *	11 ± 5	-
Garment pressure, calf (mmHg)	24 ± 4 *	10 ± 3	-
Garment pressure, thigh (mmHg)	19 ± 3 *	7 ± 3	-

Table 2. Recovery of performance and muscle damage markers over 48 h recovery

MS = muscle soreness; AU = arbitrary units; CF = custom fitted garments; SSG = standard sized garments; CON = control; CMJFpk = peak counter-movement jump force

	Group	Baseline	Post-exercise	24 h	48 h
30 m Sprint time (% baseline)	**CF**	100 ± 0	103.0 ± 2.9	101.7 ± 3.8	101.0 ± 2.8
	SSG	100 ± 0	104.9 ± 3.9	103.1 ± 4.6	103.0 ± 3.7
	CON	100 ± 0	106.0 ± 3.7	104.1 ± 3.8	105.4 ± 3.6
$CMJF_{pk}$ (% baseline)	**CF**	100 ± 0	94.4 ± 5	98.2 ± 6.7	98.0 ± 10.0
	SSG	100 ± 0	94.2 ± 8.7	97.0 ± 9.8	98.4 ± 9.8
	CON	100 ± 0	96.4 ± 12.3	97.7 ± 8.2	95.5 ± 10.2
MS (AU)	**CF**	1.0 ± 0.8	3.6 ± 1.7	3.5 ± 2.3	3.0 ± 2.4
	SSG	1.2 ± 1.3	3.7 ± 2.1	4.0 ± 2.2	3.0 ± 2.3
	CON	1.5 ± 1.5	4.7 ± 2.2	4.7 ± 1.8	3.9 ± 2.3

Table 3. Observed effect sizes of performance measures and markers of exercise induced muscle damage between conditions

Effect sizes (ES) are reported alongside 90 % confidence intervals as (ES [LCL, UCL]), where LCL and UCL represent the lower and upper 90 % confidence limits respectively. Threshold values for standardized changes were ≤ 0.2 (trivial), > 0.2 (small), > 0.5 (moderate), > 0.8 (large), where 0.2 was taken to represent the smallest worthwhile effect. ES = effect size (Cohen's d); CF = Custom fitted garments; SSG = Standard sized garments; EIMD = Exercise induced muscle damage

Time-point	Baseline	Post-exercise	24 h	48 h	Baseline	Post-exercise	24 h	48 h	Baseline	Post-exercise	24 h	48 h
Performance measures	**Lower-body strength (N)**				**Peak countermovement jump force (N)**				**30 m Sprint time (s)**			
CF	511 ± 122	451 ± 110	486 ± 106	505 ± 110	1931 ± 401	1815 ± 326	1886 ± 345	1881 ± 366	4.45 ± 0.43	4.59 ± 0.45	4.52 ± 0.42	4.49 ± 0.35
SSG	582 ± 93	491 ± 98	522 ± 93	525 ± 106	2279 ± 372	2144 ± 392	2206 ± 406	2237 ± 406	4.58 ± 0.34	4.81 ± 0.44	4.72 ± 0.38	4.71 ± 0.35
CON	589 ± 121	466 ± 99	507 ± 112	531 ± 111	2047 ± 421	1956 ± 387	1985 ± 344	1930 ± 308	4.52 ± 0.30	4.79 ± 0.33	4.71 ± 0.33	4.76 ± 0.26
EIMD markers	**Creatine kinase activity (IU)**				**Muscle soreness (AU)**				**Mid-thigh girth (cm)**			
CF	374 ± 311	464 ± 343	1018 ± 1080	616 ± 764	1.0 ± 0.8	3.6 ± 1.7	3.5 ± 2.3	3.0 ± 2.4	61.1 ± 5.4	61.1 ± 5.6	60.9 ± 5.5	61.2 ± 5.7
SSG	298 ± 231	499 ± 332	1136 ± 578	790 ± 396	1.3 ± 1.3	3.7 ± 2.1	4.0 ± 2.2	3.0 ± 2.3	65.1 ± 4.6	65.3 ± 4.8	65.5 ± 4.7	65.8 ± 5.1
CON	346 ± 522	544 ± 809	1351 ± 950	997 ± 852	1.5 ± 1.5	4.7 ± 2.2	4.7 ± 1.8	3.9 ± 2.3	62.5 ± 5.5	62.7 ± 5.4	63.0 ± 5.3	63.4 ± 5.5