Title: The effects of compression garments on performance of prolonged manual labour exercise and recovery

Running title: Compression and manual labour recovery

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Abstract

Purpose: This study investigated the effects of wearing compression garments during and 24 h following a 4-h exercise protocol simulating manual labouring tasks. **Methods:** Ten physically trained male participants, familiar with labouring activities, undertook 4 h of work tasks characteristic of industrial workplaces. Participants completed two testing sessions, separated by at least one week. In the experimental condition, participants wore a full length compression top and compression shorts during the exercise protocol and overnight recovery; with normal work clothes worn in the control condition. Testing for serum creatine kinase and C-reactive protein, handgrip strength, knee flexion and extension torque, muscle stiffness, perceived muscle soreness and fatigue as well as heart rate and perceived exertion (RPE) responses to 4-min cycling were performed before, following and 24 h after exercise. **Results:** Creatine kinase, muscle soreness and perceived fatigue increased following the exercise protocol ($p<0.05$) as did RPE to a standardised cycling warm up bout. Conversely, no post-exercise changes were observed in C-reactive protein, handgrip strength, peak knee flexion torque or stiffness measures ($p>0.05$). Knee extension torque was significantly higher in the control condition at 24 h post (3.1±5.4% change; compression: 2.2±11.1% change), although no other variables were different between conditions at any time. However, compression demonstrated a moderate-large effect ($d>0.60$) to reduce perceived muscle soreness, fatigue and RPE from standardised warm up 24 h post. **Conclusions:** The current findings suggest that compression may assist in perceptual recovery from manual labour exercise with implications for the ability to perform subsequent work bouts.

Keywords: *Industrial work, workability, muscle soreness, exercise recovery, occupational fatigue*

Abbreviations

ANOVA	Analysis of Variance
AU	Arbitrary Units
BPM	Beats Per Minute
BRUMS	Brunel Mood State Questionnaire
CHO	Carbohydrates
CK	Creatine kinase
COMP	Compression Condition
CON	Control Condition
CRP	C-reactive protein
HR	Heart rate
HR_{4min}	HR after 4 min of cycling
kg	Kilogram
N.m	Newton meter
$N\cdot m^{-1}$	Newtons per meter
RHR_{1min}	1 min Recovery Heart Rate
RPE	Rating of Perceived Exertion
RPE_{4min}	Rating of Perceived Exertion after 4 min of cycling
$U\cdot L^{-1}$	Units per Litre

Introduction

In construction and mining industries, there is a high physical demand as workers are required to lift, carry, transport and manipulate heavy loads (Hartmann et al. 2005; Maiti 2008). Movements performed in industrial worksites are often repetitive or prolonged in duration, and frequently require the individual to perform physical work in awkward, non-ergonomic postures (van der Molen et al. 2005). The physical demands of these work tasks can lead to fatigue and in turn impact on worker health and safety (Maiti 2008; Chang et al. 2009). Consequently, the term “Industrial Athlete” has been coined in recognition of the physical nature and relevance of work and recovery in these occupations.

Psychological and physiological fatigue of workers have been identified as contributing factors to workplace health and safety (Chang, Sun et al. 2009). Whilst ergonomic and mechanically assistive interventions have been developed to reduce the physical load on workers (McPhee 2004; van der Molen et al. 2005), a significant amount of work is still performed through manual labour on these sites (Parida et al. 2011). Consequently, the fatigue and recovery of workers is of foremost concern for injury preventions and productivity in the construction and mining industries (Maiti 2008; Chang et al. 2009). Given the physical nature of these industries, the application of sport-based interventions may have relevance for the Industrial Athlete to assist with their workload management and recovery.

In the sporting context, a range of strategies are used by athletes to accelerate recovery following exercise, increase their readiness to train and undertake larger training loads (Gill et al. 2006; Bahnert et al. 2013). Of interest, the use of compression garments have gained popularity in recent years, with the purpose of enhancing post-exercise recovery through increased blood circulation and venous return (Berry et al. 1987; Chatard et al. 2004;

Pruscino et al. 2013). Wearing compression garments after exercise has been found to elicit smaller decrements in subsequent power and force generation (Kraemer et al. 2001; Chatard et al. 2004; Jakeman et al. 2010), reduce metabolites and muscle damage marker concentrations (Gill et al. 2006; Duffield et al. 2007; Kraemer et al. 2010), and improve perceptual measures of recovery and fatigue i.e., muscle soreness, vitality and readiness to train (Ali et al. 2007; Duffield and Portus 2007; Davies et al. 2009; Pruscino et al. 2013).

Compression garments are commonly used by the athletic population for post-exercise recovery, however, to date there has been no research in the use of compression garments in a physical labour context. Given the high physical demand of manual labour occupations, there could be benefit in utilising compression for workplace recovery in these industries. Accordingly, the aim of this study was to investigate the effect of wearing compression garments on physiological and perceptual responses to, and recovery following, a prolonged simulated manual labouring protocol. It was hypothesised that compression garments would attenuate perceived muscle soreness and elicit a faster recovery of strength and other physiological measures relative to the control condition.

Materials and Methods

Participants

Ten healthy male participants (mean ± SD, 23 ± 3 yrs, 180.8 ± 6.4 cm, 80.8 ± 9.8 kg) volunteered to partake in this study. All participants were physically active (typically exercising at least three times per week in either team sport or resistance exercise activities) and had 1-2 years experience working in manual labour occupations (construction, landscaping, warehouse duties). However, not all participants had undertaken labour-oriented work in the recent months, and thus all were appropriately familiarised with the physical demands of the study. Following an explanation of the testing protocol, all participants gave written informed consent to engage in testing procedures, with ethical approval granted by the University Human Research Ethics Committee.

Research Design

Participants completed two testing sessions consisting of control (CON; no compression garments) and experimental; compression (COMP; long sleeve compression top and short leg pants) conditions. Respective conditions were performed in a manner consistent with a randomised cross-over experimental design, and there was a minimum of one week between the two testing sessions. A 4-h manual labour exercise protocol was performed on both occasions, with perceptual, physiological and physical tests undertaken before, immediately following and 24 h post-exercise.

Participants were required to avoid alcohol ingestion, caffeine and strenuous exercise in the 24 h prior to testing, and were provided with a standardised pre-exercise meal which was consumed 3.5 h prior to each testing session. The carbohydrate (CHO) intake for this meal was calculated using nutritional information found on product labelling and nutritional software was used to quantify the CHO value of fruit portions (Foodworks v.7, Xyris software, Brisbane, Australia). Meals were individualised based on the participant's body mass (2.5g CHO/kg body mass), and standardised to ensure uniform nutritional intake prior to each testing session. In both conditions, during the exercise protocol participants wore industry standard work clothing consisting of a cotton drill long sleeve top and full length pants (King Gee, Pacific Brands, Melbourne, Australia). For the experimental condition, participants also wore a long sleeve compression top (full length) and short leg pants (mid-thigh length) (KingGee, Pacific Brands, Melbourne, Australia), underneath the work clothing and were provided with another set to wear in the 24 h following the exercise. Compression garments were fitted according to manufacturer guidelines based on body size and anthropometrical characteristics. The exact level of compression was not measured in this study, which is noted as a limitation. The compressive long-top and shorts were selected due to the likelihood of similar garments being worn in an industrial workplace. Compression garments were not worn during any part of the pre or post-exercise testing procedures.

Exercise Protocol

Using research quantifying activities undertaken by individuals working in construction and mining industries (Hartmann & Fleischer, 2005; Maiti, 2008; van der Molen, Sluiter, Hulshof, Vink, & Frings-Dresen, 2005), an exercise protocol was created to simulate the workload of manual labour tasks. The exercise protocol consisted of a circuit of 10 stations, with participants completing two circuits to total 4 h of physical work (Table 1). Participants completed 9 min of continuous exercise at each station followed by 3 min of standing recovery (Kenny et al. 2012). The exercises were repetitive in nature and required participants to manipulate and transport moderate-heavy loads or engage in awkward postures e.g. squatting and overhead lifting, as these movements were identified as being characteristic of physical labour occupations (Hartmann and Fleischer 2005; van der Molen et al. 2005; Maiti 2008). Prior to the first testing session, participants were familiarised with the testing procedures and performed one circuit (2 h) of the exercise protocol. Participants were provided with 1.2 L of water and 0.6 L of sports drink (Gatorade, 6% CHO, 22 mmol/L Na) to fully consume *ad libitum* during the 4-h protocol. The exercise protocol was performed in an indoor gymnasium at an ambient temperature of 25.4 ± 5.5°C and 73.0 ± 12.5% relative humidity.

Experimental Procedures

Prior to, following and 24 h after the exercise protocol, participants underwent a range of perceptual, physical and physiological tests to assess fatigue and recovery from the exercise protocol. Stature was measured during the familiarisation session using a stadiometer (Holtain, Crosswell, United Kingdom). At each testing session, participants were instructed to void their bladder and record nude body mass (Lightever, Kunshan City, China). Core body temperature was measured via a telemetric capsule (Equivital, Mini Mitter, USA) which was ingested 3.5 h prior to testing. Core body temperature was recorded on the testing day, prior to, halfway through and immediately after the exercise protocol, but not 24 h post exercise. Participants wore a heart rate monitor throughout the exercise protocol (Polar Electro, Oy, Finland) and heart rate was recorded at the end of the exercise period at each respective station.

Perceptual Measures

Participants completed a Brunel Mood State Questionnaire (BRUMS) Terry, Lane & Fogarty, (2003) to assess mood state. The questionnaire consists of 24 mood descriptors, which correspond to 6 sub-categories (anger, tension, depression, confusion, vigour, fatigue). Using a 5 point Likert scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely) participants gave a rating for each mood descriptor to give a score out of 16 for each subcategory. From these measures, particular attention was paid to the subscales of anger, vigour and fatigue, as these factors contribute to workplace productivity and employee well-being (Colligan et al. 2006).

Rating of perceived muscle soreness (MS) was determined using an 11 point Likert scale (0= no soreness or normal; 3=uncomfortable; 5=sore; 8=very sore; 10=extremely sore or maximum soreness). Participants performed three shoulder rolls and half squats prior to each measurement and gave separate scores for upper and lower body muscle soreness (Duffield and Portus 2007). Rating of Perceived Exertion (RPE) was measured using Borg's category-ratio scale (0=rest; 10=maximal), which is frequently used to subjectively assess level of exercise intensity, also referred to as Borg's CR-10 RPE scale (Borg 1990). An RPE score was recorded immediately after the 4-h exercise protocol as a subjective measure of the session intensity (session RPE) (Wallace et al. 2009).

Muscle damage and blood inflammatory markers

A 10mL sample of venous blood was collected from the antecubital vein into serum separator tubes via venepuncture following 10 min of seated rest. Blood samples were left standing for 10 min before being centrifuged at 4000 rpm for 10 min. The serum from the samples was aliquoted into Eppendorf containers (Eppendorf, Germany) and frozen at -20°C for later analysis. The serum samples were defrosted to room temperature before undergoing a series of chemical and enzymatic reactions to ascertain creatine kinase (CK) and C-reactive protein

(CRP) concentration (P-800 Module-Photometric, Roche Diagnostics, Japan). The coefficient of variation for the CK analysis was 1.16-1.36% and 3.25-5.13% for CRP.

Muscle Stiffness

Passive muscle stiffness readings were obtained with a myometer device (MyotonPro, Myoton, Tallinn, Estonia) which assesses the viscoelastic properties (measured in $N.m^{-1}$) of the muscle. All muscle stiffness measures were obtained from the right side of the body using anthropometric landmarks to ensure a standardised measurement site for all testing sessions (Bizzini et al. 2003). Three upper body muscles: biceps brachii, triceps brachii and trapezius, along with one lower body muscle (rectus femoris) were measured. The measurement sites for biceps and triceps were located on the anterior and posterior aspects of the upper arm, midway between the acromion process and head of radius. Trapezius muscle stiffness was assessed midway between C7 and the acromion process. All upper body muscle stiffness measurements were recorded with the participant standing with their arms in a relaxed position by their side. Muscle stiffness for rectus femoris was assessed in a quasi-active state with the participant standing with their weight distributed evenly between both feet and also in a passive state with the participant lying down in a supine position. The testing site was located midway between the inguinal line and superior aspect of the patella. Three stiffness measures were obtained at each site via the delivery of a mechanical perturbation, with the resultant damped oscillations recorded by an in-built accelerometer sampling at 3200Hz. The mean of three measures was used for each location.

Strength Measures

Maximal wrist flexor strength of the right hand was assessed using a handgrip dynamometer (TTM, Tokyo, Japan). Hand grip strength is a test commonly used to assess upper limb function (Innes 1999). Given the large component of manual handling in physical labour tasks, this test was selected for its relevance to manual labour exercise. Participants stood with their back against a wall, holding the dynamometer in a vertical position above their head. In a controlled movement, participants would swing their arm downwards in a 180° arc, while simultaneously squeezing the dynamometer. Participants performed two maximal efforts, with 30 seconds rest between each effort. The highest score was used for subsequent analysis (Incel et al. 2002).

Peak torque for knee flexion and extension was assessed using an isokinetic dynamometer (Biodex System 3, Shirley NY, USA). Participants were seated in an upright position with hip and knee angles set at 90°; the dynamometer arm was positioned so its axis was in line with the centre of the knee joint and secured via Velcro straps. The participant's left leg and upper body were also secured via Velcro straps to prevent extraneous movement. Knee extension torque was measured as the peak force generated as the knee moved from 90° to full extension; and knee flexion torque was measured as the peak force generated as the lower leg returned to the starting position (McCleary et al. 1992). Participants were instructed to maximally contract throughout the entire phase of each movement. One set consisted of three repetitions with the dynamometer set at an angular velocity of $60°\cdot sec^{-1}$. A warm up set was performed at submaximal intensity with 60 s rest followed by the test where maximal exertion was required. The highest value achieved during one single repetition of these maximal efforts was used for data analysis.

Standardised response to exercise

Participants performed a standardised workload as follows: 4 min of sub-maximal work (175W) on a cycle ergometer (Wattbike, Nottingham, UK) followed by 1 min of seated recovery. This protocol was performed to assess acute exercise induced fatigue. Participants wore a heart rate monitor (Polar Electro, Oy, Finland) to measure heart rate (HR) which was recorded in the final 15 s of the cycling protocol (HR_{4min}) and following 1 min of seated recovery (RHR_{1min}). Borg's CR-10 RPE scale was used to record an RPE score at the end of the 4 min of cycling to provide a subjective rating of the exercise performed ($RPE_{4\ min}$).

Statistical Analysis

All data are reported as mean ± SD and analyses were performed using Statistical Package for the Social Sciences version 21 (Chicago, IL, USA). Within- and between-condition and time-point differences were assessed using two-way repeated measures ANOVA (condition x time). Post hoc analysis to determine the location of differences when a significant main effect or interactions were detected were performed using a paired *t* test with Tukey's adjustment within conditions over time and between conditions at each time point. An alpha level of 0.05 was used for all statistical procedures. Effect size analysis using Cohen's *d* was used to determine the magnitude of difference between control and COMP conditions for all corresponding variables. Effect size data representing the magnitude of difference was categorised accordingly: trivial, $d < 0.19$; small, $0.20 \leq d \leq 0.39$, moderate $0.40 \leq d \leq 0.79$; large, $d \geq 0.80$ (Cohen, 1988).

Results

Physiological variables

Physiological responses to the 4-h simulated labouring protocol for both conditions and comparative effect size data are presented in Table 2. The within-condition change for body mass indicated a significant post-exercise reduction ($p<0.05$) in both conditions, which had returned to baseline values by 24 h post. No significant difference ($p>0.05$) and trivial effect sizes were evident between conditions for body mass. Similarly, core body temperature showed a significant increase following the exercise protocol in both conditions ($p<0.05$), though no significant difference ($p>0.05$) and trivial-small effect sizes were observed between conditions. Mean HR during the simulated labouring protocol was not significantly different between conditions ($p>0.05$), alongside trivial effect sizes.

Creatine Kinase concentrations increased significantly in both conditions at post and 24 h post exercise ($p<0.05$). However, no significant differences ($p>0.05$) and small-moderate effect sizes were evident between conditions. Additionally, no significant within- or between-group differences ($p>0.05$) were present for CRP, with trivial-moderate effect sizes evident between conditions.

Muscle strength and stiffness

Muscle strength and stiffness measures are presented in Table 3. No significant differences were found within or between conditions for maximal hand grip strength or knee flexion torque ($p>0.05$), with trivial-small effect sizes evident between conditions immediately and 24 h post-exercise. Maximum knee extension torque was reduced ($p<0.05$) in both conditions following the exercise protocol, but returned to baseline values by 24 h post. The increase from post to 24 h was only found to be significant within the CON condition (3.1±5.4% change, $p<0.05$); but not COMP condition (2.2±11.1% change, $p>0.05$). Between conditions, significant difference ($p<0.05$), and trivial-small effect sizes were observed for knee extension torque; with post-hoc analysis showing a significant increase (7.9%±14.5) between post and 24 h post measures in the CON condition.

A significant time interaction effect was observed for quadriceps (lying) muscle stiffness in both conditions with a decrease in stiffness between pre and post-exercise measures (Control: -6.9±4.6%, $p<0.05$; COMP: -5.8±6.4%, $p<0.05$). For 24 h post measures, stiffness increased from post-exercise but did not return to baseline values. In the CON condition, this reduction from pre-exercise values (-4.6±5.8%) was found to be significant ($p<0.05$), but was not for the COMP condition (-2.9±4.6%, $p>0.05$). Similarly, significant differences were found for the decrease in triceps stiffness post-exercise in the COMP condition (-6.3±5.2%; $p<0.05$), but not in the CON condition (-1.4±8.0%).

Between condition analysis revealed a significant difference for triceps muscle stiffness ($p<0.05$). Post-hoc analysis revealed that the COMP condition yielded a significant 6.3±5.9% ($p<0.05$) decrease between pre-post exercise values, compared to a negligible (1.4±7.98%; $p>0.05$) change in CON condition. No significant differences and trivial-small effect sizes were evident for all other muscle stiffness measures; though a moderate effect size (d=0.55) was evident for higher trapezius muscle stiffness 24 h post exercise in the control condition.

Perceptual measures

The results for muscle soreness, perceived anger, fatigue, vigour and RPE for the 4 h simulated labouring protocol for both conditions and comparative effect size data are presented in Table 4. A significant time interaction effect was evident in both conditions with an increase in both upper and lower body muscle soreness ($p<0.05$). Between condition analysis found no significant difference ($p>0.05$), yet moderate-large effect sizes (d=0.59-0.88) were evident for increased upper body MS and moderate effect sizes (d=0.45-0.53) for lower body MS post and 24 h post-exercise in the compression condition. In both conditions, perceived fatigue increased significantly immediately following and 24 h after the exercise protocol ($p<0.05$). Between conditions, there was no significant difference and moderate effect sizes for perceived fatigue (*d*=0.44-0.72). No significant differences were evident within or between conditions for perceived anger and vigour with trivial-moderate effect sizes between conditions. Session RPE was not significantly different ($p<0.05$) and trivial effect sizes were observed between conditions.

Standardised response to exercise

Table 5 presents HR and RPE data recorded after 4-min cycling and 1-min seated recovery performed pre, post and 24 h post exercise. HR_{4min} and RHR_{1min} were significantly higher following the exercise protocol in both conditions ($p<0.05$), though returned to baseline values by 24 h post. The RPE measured after 4 min of cycling was significantly higher ($p<0.05$) following the 4 h labouring protocol exercise in the CON condition, though not in the COMP condition ($p>0.05$). However at 24 h post, RPE_{4min} had returned to baseline levels in both conditions ($p>0.05$). No significant difference was found between conditions for any variables assessed during the cycling protocol. Moderate effect sizes were found for RPE_{4min} at post and 24 h post time points, and for RHR_{1min} at the 24 h post exercise time point (*d*=0.51). All HR_{4min} measurements and post exercise RHR_{1min} were trivial-small in effect size.

Discussion

The purpose of this study was to investigate the influence of compression garments on the physiological and perceptual responses to, and recovery following prolonged manual labour. Though not statistically significant, moderate-large effects were demonstrated for reduced perceptual measures of muscle soreness and fatigue immediately and 24 h following exercise, and perceived exertion of 4-min cycling in the compression condition. A significant difference was observed for peak knee extension torque between conditions ($p<0.05$), with higher post and 24 h post values in the CON condition. However, no differences were evident for any other force production measure or physiological response to exercise between conditions. Accordingly, it appears that wearing compression garments during and following a simulated prolonged manual labour protocol may improve perceptual measures of recovery and perceived work readiness.

The simulated manual labour protocol used in the current study was physically demanding to replicate the type of manual workload regularly undertaken by industrial-based workers (Hartmann and Fleischer 2005; Maiti 2008). Following the exercise protocol, there was an increase in CK concentration, perceived level of fatigue and perceived muscle soreness, indicating the exercise protocol was of an adequate physical load and intensity to induce muscular damage and fatigue observed in industrial worksites (Hartmann and Fleischer 2005; Kraemer et al. 2010; Jakobsen et al. 2014). Participants rated the exercise protocol as “hard” on the Borg CR-10 RPE scale, which is reflective of high muscular loading experienced during manual labour tasks (Jakobsen et al. 2014).

Despite the demands mentioned above, there were no decrements for hand grip strength or peak knee flexion torque observed following the exercise protocol and no difference between conditions. Knee extension torque decreased following the exercise protocol, increased at the 24 hr time point to exceed baseline values in the CON condition. The lack of observed change in peak force production may have been a factor limiting the ability of compression to improve muscular function. Whilst manual labour is of low intensity, movements are repetitive and performed over a prolonged period of time; and consequently result in a large volume of muscular work (van der Molen et al. 2005). As this was the first study to assess the influence of compression on manual labour exercise, it can now be confirmed that compression has no effect on handgrip strength following this type of exercise. These findings support previous research where compression has only been found to be effective in the restoration of muscular force in studies of maximal eccentric work or where a high level of muscle damage has occurred (Kraemer et al. 2001a; Kraemer et al. 2001b; Gill et al. 2006; Duffield and Portus 2007).

The manual labour protocol resulted in an increase in CK concentrations following exercise; however, no differences were observed between conditions at any time point. This result is consistent with the research where many studies report no changes in CK concentration when compression is applied post-exercise (Duffield et al. 2008; Davies et al. 2009; Pruscino et al. 2013). In other physiological measures, no differences were evident between conditions for heart rate and core body temperature during the 4-h exercise protocol. These findings are in agreement with (MacRae et al. 2012), who reported compression garments had minimal effect on cardiac variables and core body temperature during a standardised cycling protocol (60-min fixed load cycling and 6 km time trial). MacRae et. al. (2012) suggested that compression had minimal influence on cardiovascular function during exercise as circulatory function is already optimised during dynamic exercise.

Further, the application of compression in medical contexts has been found to enhance blood circulation and venous return in clinical populations, and be most effective when applied to the lower limb (Lawrence et al. 1980; Agu et al. 1999). Enhancing venous return may be beneficial to recovery via improvement in metabolite removal and increased circulation to limbs (Berry et al. 1987; Chatard et al. 2004). One of the limitations of this study was the length of mid-thigh level compression shorts worn by participants, which could have potentially limited the efficacy of the compression intervention. Although the short length of the shorts may limit compression, the reality of full-length compression garments being worn in mining/labouring industries is unlikely, thus the current apparel was chosen. Accordingly, the effect of compression on manual labour exercise via full length compression tights or calf socks remains an area for further research. Further, although the compression garments were fitted to participants according to manufacturer's recommendations, it has been reported that compression applied via sport compression garments is variable according to sizing and posture (Brophy-Williams et. al., 2014) It is acknowledged that a limitation of this study is that the level of compression was not measured.

Muscle stiffness represents the amount of stiffness residing within the muscle-tendon unit and affects the rate of force development (Wilson et al. 1991; Brughelli et al. 2008). In this study, muscle stiffness decreased following the exercise protocol, potentially as a result of the exercise-induced increase in body temperature and changes to musculotendinous properties following 4-h manual labour exercise (Brughelli and Cronin 2008; Ditroilo et al. 2011). Wearing compression garments during and 24 h post-exercise, was only found to affect the triceps musculature, while no difference was observed for other muscles measured. Given the trivial-small effect of compression on stiffness response observed in other muscles, it is possible that the style of compression garments, being long-sleeved, specifically affected the triceps. Furthermore, many of the activities in the exercise protocol (see Table 1) involved a muscular contraction of the triceps muscle, i.e. lifting, carrying, pushing resulting in a large load on this muscle group. The difference in triceps stiffness following recovery may have been due to a higher degree of muscle fatigue and subsequent greater magnitude for improvement given the smaller muscle capacity and heightened activation of triceps in the exercise protocol for lifting activities.

In the current study, compression demonstrated moderate-large effects on improved perceptual measures of fatigue, muscle soreness and recovery. Specifically, a moderate effect on perceived muscle soreness post-exercise and large effect for reduced upper body muscle soreness 24 h post-exercise was observed in the compression condition. Whilst there was a trend for higher muscle soreness in the control condition at baseline, this difference was not significant ($p>0.05$). Consequently, caution is warranted when interpreting these results. Previous literature has reported a common trend for reduced perceived muscle soreness from wearing compression garments for post exercise recovery (Duffield et al. 2008; Davies et al. 2009; Duffield et al. 2010; Jakeman et al. 2010; Pruscino et al. 2013). Wearing compression had a moderate effect on perceived fatigue and perceived exertion for the 4-min cycling test performed post-exercise. These findings agree with previous research where lower levels of fatigue, improved vitality and enhanced recovery were reported when compression garments were worn following exercise (Kraemer et al. 2000; Pruscino et al. 2013). Additionally, (Kraemer et al. 2000) demonstrated that wearing compression hosiery was beneficial in mediating discomfort of the lower limbs elicited from 8 h of prolonged standing. Given the predominance of prolonged standing for work duties in industrial worksites (Halim et al. 2011), compression may be useful in alleviating perceived discomfort and fatigue, and potentially enhance work readiness and productivity for manual labour workers (Kraemer et al. 2000). However, in the absence of participants being blinded to the compression condition, a placebo effect from the compression condition cannot be excluded as influencing perceptual responses (Duffield et al. 2008; Duffield et al. 2010; Pruscino et al. 2013).

Finally, in the current study, fatigue and recovery were assessed after one 4-h session of work. It is possible over consecutive work shifts and higher volumes of work, compression could demonstrate a greater effect on testing measures. (Montgomery et al. 2008) reported that wearing compression post-exercise during a three day basketball tournament had moderate-large effect on improving perceived fatigue and muscle soreness relative to passive recovery. It is recognised that a one-off 4-h shift does not represent the consecutive day and 8-12 h duration shift of many manual labourers. The exercise protocol utilised in the current study was successful in using manual labour tasks to elicit the physical demands of an industrial workplace, and the findings demonstrate the role of compression to improve perceptual responses to fatigue and muscle soreness. Future research should investigate the effect of compression over a longer period of time and consecutive days or shifts, which will allow the effect of cumulative fatigue to be assessed.

Conclusion

Compression garments had minimal influence on performance or recovery from a 4-h manual labour exercise protocol. Although there were no differences in strength or physiological parameters, compression garments appeared to have a positive moderate-large effect on perceptual measures in the recovery period following the exercise protocol, though was not statistically significant. Despite the possibility of a placebo effect, use of compression was effective in reducing levels of perceived muscle soreness, perceptual fatigue and ratings of exertion during subsequent exercise workloads. These outcomes may benefit manual labour workers in improving their work readiness, by decreasing perceived fatigue and perception of physical work and muscle soreness.

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TABLES

Table 1 Exercise protocol, sequence and equipment list for the simulated manual labour protocol. Each station was 9 minutes in duration/3 min rest.

Station	**Load**	**Instructions**	**Workload**
Stairs (50 stairs total)	2 x 10 kg weight plates	Start at top of the stairs, walk down, take stairs up two at a time. Carry weight plates in each hand.	One effort every min
Log weight carry	2 x 15 kg log weights	Carry log weights and walk 40 m.	One effort every min
Shelf Stacking	3 x 6.5 kg boxes Place on boxes 30, 45 and 60 cm high	Pick up weight off box, squat down and put on the ground. Move to the next box and repeat. Once all the boxes are off, put them back on.	One effort every 30 sec
Tyre stack	4 x tyres *Total weight 15.6 kg*	Pick up two tyres, hold at chest height so they are horizontal, walk 20 m.	One effort every 30 sec
Sledgehammering	Sledgehammer Tyre stack (1.2 m high) *Sledgehammer 12 kg*	Hit tyres with sledgehammer, start hammer at hip height. Hit at a consistent rate and force.	Continuous 10 hits every 30 sec
Vibration platform	Continuous half squats or calf raises for 1 min	Perform half squats and calf raises with feet shoulder width apart, Vibration platform set to 26 Hz.	One effort every min with 30 sec rest
Box carrying	2 x boxes *Total weight 33 kg*	Pick up two boxes, walk with boxes for 60 m.	One effort every min
Overhead lifting	1 x 10 kg weight plate	Hold 10 kg weight plate above head – keep arms slightly bent, elbows pointing forward.	One effort every min with 30 sec rest
Trolley	*Total loadincluding trolley 70 kg*	Push loaded trolley up and down ramp in a controlled manner. Ascend ramp walking backwards.	One effort every 30 sec
Heavy Rope Pull	Rope gather *(10 m x 10 cm thickness, 15 kg)*	Lay rope out to full length then pull the entire length of rope in.	One effort every 30 sec

Table 2: Body mass, core temperature, heart rate, creatine kinase and C-reactive protein for Control vs. Compression Garment condition at pre, post and 24 h post-exercise (values are mean ± SD).

Variable		**Control (n = 10)**	**Compression (n = 10)**	**Effect Size (Cohen's *d*)**	**Condition main effect p value**
Body Mass (kg)	Pre	80.68 ± 9.83	80.82 ± 9.82	0	0.49
	Post	79.83 ± 9.75*	79.79 ± 9.70*	0	
	24 hr	80.56 ± 9.66$^{\#}$	80.72 ± 9.83$^{\#}$	0	
Core Temp (°C)	Pre	36.9 ± 0.2	36.9 ± 0.2	0	0.80
	During	37.6 ± 0.4*	37.4 ± 0.5	0.10	
	Post	37.7 ± 0.4*	37.5 ± 0.4*	0.30	
Creatine Kinase (U.L^{-1})	Pre	207 ± 96	267 ± 146	0.48	0.88
	Post	368 ± 117*	435 ± 222*	0.38	
	24 hr	313 ± 118*	363 ± 187*	0.32	
C-reactive protein (U.L^{-1})	Pre	0.42 ± 0.21	0.78 ± 0.66	0.69	0.45
	Post	0.43 ± 0.22	0.73 ± 0.56	0.69	
	24 hr	1.09 ± 1.19	1.21 ± 0.77	0.13	
HR$_{Exercise}$ (bpm)	During	129 ± 13	129 ± 11	0	0.99

* significantly different from pre-exercise time point within same condition ($p<0.05$).

significantly different from post-exercise time point within same condition ($p<0.05$).

Table 3: Muscle strength and stiffness for Control vs. Compression Garment condition taken pre, post and 24 h post exercise (values are mean ±SD)

Variable		**Control (n = 10)**	**Compression (n = 10)**	**Effect Size (Cohen's *d*)**	**Condition main effect p value**
Grip Strength (kg)	Pre	50.8 ± 5.2	53.4 ± 7.5	0.40	0.19
	Post	48.7 ± 5.3	50.3 ± 3.9	0.36	
	24 h	51.4 ± 5.7	50.1 ± 3.9	-0.26	
Knee flexion peak torque (Nm)	Pre	140 ± 13	142 ± 17	0.15	0.14
	Post	146 ± 11	139 ± 21	-0.39	
	24 h	143 ± 14	139 ± 16	-0.29	
Knee extension peak torque (Nm)	Pre	272 ± 34	273 ± 39	0.03	0.04$^{\wedge}$
	Post	269 ± 43	258 ± 44	-0.27	
	24 h	277 ± 42$^{\#}$	266 ± 41	-0.28	
Bicep Stiffness (N.m^{-1})	Pre	218 ± 25	221 ± 21	0.14	0.81
	Post	209 ± 22	213 ± 20	0.23	
	24 h	211 ± 19	216 ± 14	0.34	
Triceps Stiffness (N.m^{-1})	Pre	222 ± 29	227 ± 30	0.20	0.00$^{\wedge}$
	Post	221 ± 38	213 ± 20*	-0.24	
	24 h	229 ± 33	216 ± 20	-0.49	
Trapezius Stiffness (N.m^{-1})	Pre	322 ± 50	340 ± 57	0.33	0.24
	Post	325 ± 35	312 ± 36	-0.37	
	24 h	312 ± 43	337 ± 47	0.55	
Standing Quad Stiffness (N.m^{-1})	Pre	314 ± 44	332 ± 95	0.25	0.22
	Post	297 ± 34	296 ± 42	-0.05	
	24 h	315 ± 49	333 ± 80	0.27	
Lying Quad Stiffness (N.m^{-1})	Pre	286 ± 27	284 ± 39	-0.05	0.78
	Post	266 ± 25*	267 ± 34*	0.03	
	24 h	273 ± 32$^{*\#}$	276 ± 39	0.09	

* significantly different from pre-exercise time point within same condition ($p<0.05$).

significantly different from post-exercise time point within same condition ($p<0.05$).

$^{\wedge}$ significant difference between conditions ($p<0.05$).

Table 4: Upper and lower body muscle soreness^, perceived anger, fatigue and vigour levels and session RPE for Control vs. Compression Garment condition taken pre, post and 24 h post exercise (values are mean ±SD)

Variable		**Control (n = 10)**	**Compression (n = 10)**	**Effect Size (Cohen's *d*)**	**Condition main effect p value**
MS_{Upper} (0-10)	Pre	1.2 ± 1.5	0.8 ± 0.9	-0.32	0.52
	Post	5.1 ± 2.0*	4.0 ± 1.5*	-0.59	
	24 h	4.7 ± 2.6*	2.6 ± 1.8*#	-0.88	
MS_{Lower} (0-10)	Pre	1.7 ± 1.7	0.9 ± 1.1	-0.54	0.07
	Post	4.5 ± 1.2*	4.0 ± 0.9*	-0.45	
	24 h	4.0 ± 1.7*	3.1 ± 1.8*#	-0.53	
Perceived Anger (AU)	Pre	0.2 ± 0.6	0.6 ± 0.97	0.49	0.33
	Post	0.8 ± 1.6	0.4 ± 0.97	-0.30	
	24 h	0.7 ± 1.5	0.2 ± 0.42	-0.44	
Perceived Fatigue (AU)	Pre	3.9 ± 3.5	2.5 ± 2.6	-0.45	0.83
	Post	7.7 ± 2.0*	5.7 ± 3.1*	-0.72	
	24 h	3.8 ± 3.4#	2.5 ± 2.4#	-0.44	
Perceived Vigour (AU)	Pre	8.6 ± 4.2	8.6 ± 2.5	0.00	0.82
	Post	6.5 ± 3.8	6.4 ± 4.7	-0.02	
	24 h	7.8 ± 3.2	8.9 ± 2.8	0.36	
$RPE_{Session}$ (AU)	Post	5.4 ± 1.5	5.3 ± 1.3	-0.07	0.79

^ as stated in the Methods section, muscle soreness scale descriptors are as follows: (0= no soreness or normal; 3=uncomfortable; 5=sore; 8=very sore; 10=extremely sore or maximum soreness).

* significantly different from pre-exercise time point within same condition (p<0.05).

significantly different from post-exercise time point within same condition (p<0.05).

Table 5: Heart rate and RPE following 4 min cycling with 1 min recovery for Control vs. Compression condition taken pre, post and 24 h post exercise (values are mean ±SD)

Variable		**Control (n = 10)**	**Compression (n = 10)**	**Effect Size (Cohen's *d*)**	**Condition main effect p value**
HR_{4min} (bpm)	Pre	130 ± 15	130 ± 14	-0.04	0.63
	Post	$141 \pm 20^{*}$	$141 \pm 13^{*}$	0.06	
	24 h	134 ± 14	$131 \pm 11^{\#}$	-0.20	
RPE_{4min} (0-10)	Pre	2.7 ± 1.2	2.6 ± 1.0	-0.05	0.45
	Post	$3.9 \pm 1.1^{*}$	3.4 ± 0.6	-0.55	
	24 h	$3.0 \pm 1.0^{\#}$	$2.6 \pm 0.5^{\#}$	-0.43	
RHR_{1min} (bpm)	Pre	91 ± 17	89 ± 15	-0.13	0.15
	Post	$109 \pm 17^{*}$	$108 \pm 18^{*}$	-0.09	
	24 h	$93 \pm 14^{\#}$	$86 \pm 15^{\#}$	-0.51	

* significantly different from pre-exercise time point within same condition ($p<0.05$).

significantly different from post-exercise time point within same condition ($p<0.05$).

HR_{4min} = heart rate post 4 minutes of cycling, RHR_{1min} = Recovery heart rate following 1 min of seated recovery, $RPE_{4\ min}$= RPE reported post 4 min cycling