Published ahead of Print

The Acute Effects of Compression Garments on Muscle Protein Synthesis Markers, Blood Flow, Performance, and Perceived Recovery after Resistance Exercise

Alana J. Leabeater[1], James R. Broatch[2], Matthew W. Driller[1], Lachlan P. James[1], Melpomeni Malamouli[2], Shona L. Halson[3,4], David J. Bishop[2], Andrew Garnham[2], and Shane F. O'Riordan[2]

[1]Sport, Performance and Nutrition Research Group, School of Allied Health, Human Services, and Sport, La Trobe University, Melbourne, AUSTRALIA; [2]Institute for Health and Sport (IHES), Victoria University, Melbourne, AUSTRALIA; [3]School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, QLD, AUSTRALIA; [4]Sports Performance, Recovery, Injury and New Technologies (SPRINT) , Australian Catholic University, Brisbane, QLD, AUSTRALIA; Research Centre, Australian Catholic University, Brisbane, QLD, AUSTRALIA

Accepted for Publication: 14 April 2025

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000003741

The Acute Effects of Compression Garments on Muscle Protein Synthesis Markers, Blood Flow, Performance, and Perceived Recovery after Resistance Exercise

Alana J. Leabeater[1], James R. Broatch[2], Matthew W. Driller[1], Lachlan P. James[1], Melpomeni Malamouli[2], Shona L. Halson[3,4], David J. Bishop[2], Andrew Garnham[2], and Shane F. O'Riordan[2]

[1]Sport, Performance and Nutrition Research Group, School of Allied Health, Human Services, and Sport, La Trobe University, Melbourne, AUSTRALIA; [2]Institute for Health and Sport (IHES), Victoria University, Melbourne, AUSTRALIA; [3]School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, QLD, AUSTRALIA; [4]Sports Performance, Recovery, Injury and New Technologies (SPRINT) , Australian Catholic University, Brisbane, QLD, AUSTRALIA; Research Centre, Australian Catholic University, Brisbane, QLD, AUSTRALIA

Address for correspondence:

Alana J Leabeater, Health Sciences 2, Office 104, La Trobe University, Melbourne, Victoria, Australia, 3086; E-mail: a.leabeater@latrobe.edu.au

Conflicts of Interest and Source of Funding

The authors report there are no competing interests to declare. The authors wish to thank Stephanie Davies and Jo Miller of the Australian Institute of Sport for their assistance and for providing some

of the compression tights used in the study. The remaining allocation of compression tights used in the current study were supplied by the company (Pressio Inc., London, United Kingdom) free of charge; however, the company had no input into the design, analysis, or reporting of results from this study. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

ABSTRACT

Introduction/Purpose: Compression garments are a commonly used recovery aid following resistance exercise, which may improve muscle blood flow and perceived recovery. However, there has been limited insight into the underlying molecular mechanisms that may mediate the physiological effects of compression garments. The aim of this study was to investigate the effect of compression tights on markers of muscle protein synthesis, muscle blood flow, and indices of recovery following a bout of resistance exercise. **Methods:** Twenty resistance-trained participants (5 females, 15 males) completed a leg-press exercise session followed by a 5-h recovery period wearing either commercially available compression tights (COMP, n = 10) or no tights (CON, n = 10). Physiological (markers of muscle protein synthesis, muscle blood flow, blood lactate, blood glucose), perceptual (total quality of recovery, perceived muscle soreness and subjective wellbeing), and performance measures (countermovement jump and isometric mid-thigh pull) were collected at baseline, immediately post-exercise (performance and perceptual only), and at 1-h (physiological and perceptual only), 5-h and 24-h post-exercise. **Results:** No significant ($p <$ 0.05) interactions were observed between groups in physiological, performance, and perceptual measures. There were main effects of time for post-exercise measures compared to baseline ($p <$ 0.05), with increased markers of muscle protein synthesis, muscle blood flow, blood lactate, muscle soreness, and reduced blood glucose, total quality of recovery, subjective wellbeing, and countermovement jump height for both groups. **CONCLUSIONS:** Commercially available compression tights used post-resistance exercise did not influence muscle protein synthesis markers, muscle blood flow or indices of exercise recovery following resistance exercise in the current study. **Key Words:** RECOVERY INTERVENTION, MUSCLE SORENESS, STRENGTH, ADAPTATION

INTRODUCTION

Resistance exercise is a form of exercise that seeks to increase lean muscle mass, improve strength and power and assist in the prevention of injuries (1). Individuals performing resistance exercise may later experience symptoms of exercise-induced muscle damage (EIMD), including tissue oedema and reductions in maximal force capacity, though these are more common from unfamiliar or unaccustomed training (2). The resultant increase in pain sensation, otherwise known as delayed-onset muscle soreness (DOMS), can impair movement patterns and perceptual measures of recovery and possibly demotivate individuals to participate in subsequent training (2). To help mitigate the deleterious effects of DOMS and EIMD after resistance exercise and maximise subsequent training volume and quality, individuals may choose to implement recovery aids, with compression garments being a popular choice.

Originally used in clinical and therapeutic settings for the treatment of pulmonary emboli, oedemas and deep vein thrombosis, compression garments apply mechanical pressure to the body and are used to improve blood flow and circulation (3). In turn, this may promote enhanced recovery following a resistance exercise session when compared to no recovery intervention, as indicated by improvements in muscle strength (4, 5) and countermovement jump (CMJ) height (6-8), as well as reductions in perceived muscle soreness (4, 6). Conversely, other investigations have reported no changes to CMJ height (9) or measures of lower and upper-body power (10) after using compression garments for 12-24 hours recovery following a resistance exercise session. These conflicting findings may reflect the variability in commercially available compression garments used for research, as the effectiveness of the garments in improving indices of exercise recovery can be dependent on garment pressure, composition and fit (6).

One key mechanism by which compression garments may mediate improvements in recovery after resistance exercise is through changes to muscle blood flow. Subsequently, this may increase the clearance of metabolic waste products and the delivery of nutrients following exercise (11-13). For example, compression tights used during a 4-h recovery period following resistance exercise were shown to increase muscle blood flow and markers of venous return, which was associated with enhanced physical and perceptual recovery in resistance-trained individuals (14). However, a contradictory effect on blood flow appears to take place at the microvascular level, whereby muscle microvascular perfusion after exercise may be attenuated with the use of compression garments, which could subsequently influence nutrient uptake and related pathways involved in muscle protein synthesis (15). It is also apparent that the effect of compression garments on blood flow is dependent on applied garment pressure, whereby too little pressure will have no effect (16) and excessive garment pressure may hinder blood flow (17). This is pertinent given that the applied pressure of commercially available compression garments can vary considerably between manufacturers (18), as well as between individuals (19).

Resistance exercise has been shown to increase skeletal muscle blood flow, contributing to enhanced transport and delivery of amino acids necessary to stimulate muscle protein synthesis (20, 21). In response to a single session of resistance exercise, there is an elevation of muscle protein synthesis for up to 24–48 h (22), which can be attributed to the activation (phosphorylation) of protein kinases that include mammalian target of rapamycin (mTOR), p70S6 kinase (p70S6K) and ribosomal protein S6 (rps6) (23). These protein kinases are directly involved in the translation of proteins necessary for muscle growth, adaptation, and repair, as well as in stimulating mixed muscle protein synthesis (24). Though there is considerable heterogeneity between individuals, measuring changes in the content and phosphorylation of these proteins can provide insight into an individual's adaptation to the resistance exercise stimulus (25, 26) and, potentially, the capacity for muscle hypertrophy over time. For example, increased phosphorylation of p70S6k following an initial resistance exercise session has been associated with increased fat-free mass and muscle fibre cross-sectional area after a training program (23). While there is ample evidence to suggest compression garments may enhance recovery from resistance exercise (4, 6, 7, 14, 27), there has been no insight into the underlying molecular mechanisms that may mediate the observed physiological effects of the garments. Examining the changes in protein content and phosphorylation modulated by specific recovery strategies such as compression garments will ultimately contribute to a greater understanding of their overall role in physiological adaptation to training. Therefore, the compression-induced changes in blood flow during recovery from resistance exercise may also influence the complex molecular process of muscle protein synthesis.

Recent research on recovery strategies such as cold-water immersion (CWI) has drawn into question the role that such strategies may play in acute hypertrophy signalling (e.g., mTOR, p70S6K) and molecular adaptations (i.e., muscle hypertrophy, muscular strength) over time. While regular CWI use after resistance exercise may blunt molecular signalling when used regularly (28-30), hot water immersion, a post-exercise strategy that aims to promote muscle blood flow and has similar proposed mechanisms to compression garments, has been reported to improve key markers of muscle protein synthesis and muscle hypertrophy (31). However, these findings are not consistent (32, 33), and future research is required to investigate the effect of strategies (i.e., compression garments) that may alter post-exercise muscle blood flow on markers of muscle protein synthesis. Furthermore, identifying the acute molecular responses and physical performance effects of compression garment use following resistance exercise will provide the initial insight for further research on the efficacy of long-term compression garment use and the potential implications for training adaptations (e.g., muscle hypertrophy, muscular strength). Therefore, the primary aim of this study was to assess, for the first time, the effect of compression garments used for recovery on markers of muscle protein synthesis post-resistance exercise. A secondary aim was to assess the influence of compression garments on muscle blood flow and indices of muscle recovery.

METHODS

Participants

In the current study, 28 adults volunteered to participate, of which 8 were found to be ineligible due to injury, contraindications to exercise, or training status. The final sample consisted of 20 adults (5 females; 15 males) (Table 1). The sample size was powered to detect a medium (d = 0.55) difference at a = 0.05 and $ß$ = 0.2 (G*Power Version 3.1.9.7; Universität Düsseldorf, Düsseldorf, Germany), using previously reported differences in blood flow at the *vastus lateralis* with and without compression tights (14). To minimise large variations in response to the exercise intervention, all participants were required to be participating in at least two resistance exercise sessions per week (including lower-body exercises) for the previous six months to be eligible to participate. All participants were screened to ensure they did not have any contraindications that may have affected their ability to perform the physical performance testing or use the recovery intervention (e.g., joint pain or musculoskeletal injury). Written informed consent was obtained from each participant, and ethical approval was obtained from the Victoria University Human Research Ethics Committee of the institution (HRE19-094). Participants were matched one-on-one for strength (by 1-repetition maximum (1RM) leg press result) and then randomly divided as a pair into one of two recovery groups prior to Visit 2. These groups were sports compression tights (COMP, 2 females and 8 males, n = 10) and a passive control group (CON, 3 females and 7 males, n = 10). Female participants could voluntarily report details of their menstrual cycle on a questionnaire at the start of Visit 2, as recommended by Elliott-Sale, Minahan (34).

Experimental Overview

A parallel group design was used for the present study. Participants were allocated to an experimental (COMP) or control (CON) recovery intervention in a randomised design. Participants first completed a familiarisation session (Visit 1) of the testing protocols and performance measures (CMJ, isometric mid-thigh pull (IMTP) and assessment of muscle blood flow (near-infrared spectroscopy; (NIRS)) used in the study and performed 1RM leg press testing. Participants then reported to the laboratory 10 to 14 days later for an acute trial (Visit 2), consisting of pre-testing (perceptual ratings, resting muscle biopsy, NIRS, CMJ and IMTP) prior to a resistance exercise intervention (leg press exercise). Performance and perceptual measures were repeated immediately post-exercise before the application of either compression tights (COMP) or no recovery intervention (CON) for a 5-h period. During this period, perceptual measures, NIRS, muscle biopsies and performance measures were repeated as per Figure 1. Participants then returned to the laboratory for a 24-h follow up visit (Visit 3), where all physical and perceptual measures were repeated.

Procedures

Muscle Biopsies. Muscle biopsies were sampled by a trained physician at four time points (Figure 1) from the *vastus lateralis* muscle using a suction-modified 5-mm Bergström needle (35, 36). New incisions were made on the same leg for each time point (i.e., baseline, 1-h post, 5-h post and

24-h post-exercise). Under local anaesthesia (1% lidocaine), a small incision was made through the skin, subcutaneous tissue and fascia overlying the *vastus lateralis*, using sterilised equipment and aseptic techniques. The needle was inserted into the muscle, and a small (~50 to 100 mg) portion of muscle tissue was removed. All muscle samples were snap-frozen in liquid nitrogen and stored at -80°C for later analysis.

Immunoblotting of Muscle Protein Markers. Frozen muscle samples (~5 to 10 mg) were first lysed in RIPA buffer (25 mM Tris Hydrochloride, pH 7.6, 150 mM sodium chloride, 1% NP-40, 1% sodium deoxycholate, 0.1% sodium dodecylsulphate) with the addition of a phosphate and protease inhibitor cocktail at 1:100. To assess total protein concentration in whole muscle lysates, a protein assay kit was used (Pierce™ BCA Protein Assay Kit; Thermofisher). All samples were subsequently treated in a 4 x Laemmli buffer containing beta-mercaptoethanol and subjected to boiling at 95 °C for 5 min. 20 µg micrograms of protein (10 microliters of samples of a 2mg/ml concentration) were loaded in each well on 4–20% Criterion™ TGX Stain-Free™ Protein Gels. Each gel also contained internal standards (pooled samples from all lysates). Samples and standards were separated via electrophoresis (Criterion™ Vertical Electrophoresis Cell, Biorad) for ~150 min at 80-100 V before transfer onto a low-fluorescence polyvinylidene difluoride (PVDF) membrane using the Trans-Blot® Turbo™ Transfer System (1.2 A, 25 V, for 10 min). Membranes were blocked for 1-h in 5% bovine serum albumin in Tris-buffered saline (TBS) and 0.1% Tween 20 (TBS-T). After 3 × 5-min washes in TBS-T, membranes were incubated overnight at 4°C with gentle agitation in primary antibody solutions (1:1000 antibody in 5% BSA, plus 0.02% sodium azide). The primary antibodies used were from Cell Signaling Technologies and include 4E-BP1 (#9452), phospho-4E-BP1 (#2855), eF2 (#2332), phospho-eF2 (#2331), mTOR

(#2983), phospho-mTOR (#5536), p70S6K (#9202), phospho-p70S6K (#9234), rps6 (#2217) and phospho-rps6 (#4856). The following day, membranes were washed for 3 x 5-min in TBS-T and incubated for 70 min in the appropriate dilution of secondary horseradish peroxidase-conjugated antibody. After another wash of 3 x 5 min with TBS-T, proteins were visualised using ultra-sensitive enhanced chemiluminescence (SuperSignal™ West Femto Maximum Sensitivity Substrate, Thermo Scientific) or enhanced chemiluminescence (ECL) substrate (clarity western ECL substrate, Biorad) and were quantified through densitometry. Images of membranes for total protein and targeted protein bands were analysed using Image Lab, version 6.0.1 (Biorad) to determine band density. Subsequently, the band density data was normalised for each lane to both the total protein content and the internal standard loaded in each gel. From a maximum of 80 samples per target protein, some samples were excluded from the final analysis due to technical issues during the western blot assay (Table 2). The activation ratio for each target protein was then quantified by dividing the phosphorylated protein content by the total protein content.

Muscle Blood Flow. Muscle blood flow was measured at the *vastus lateralis* muscle using NIRS at four timepoints as indicated in Figure 1. One oximeter was secured with double-sided tape on the lowest third of the *vastus lateralis* muscle on the participant's right leg, directly opposite the muscle biopsy site on the participant's left leg. The placement site was shaved of excess hair (if required) and a quadriceps skinfold was taken from each participant to ensure a good quality signal at this location (< 35 mm) as used in previous studies (37). The quadriceps skinfolds for all participants were deemed acceptable for accurate measurement of blood flow with NIRS (Table 1). Using an automated rapid cuff inflation system (Hokanson, Washington, USA), three 20-s venous occlusions of 70 mmHg were applied to the participant's upper right thigh with a pressure cuff, separated by 45-s of rest. Data from the oximeter was recorded and later analysed using proprietary computer software (Oxysoft V3.0.53, Artinins Medical Systems, The Netherlands). Blood flow into the muscle was calculated by the rise in total haemoglobin (tHb) (O_2Hb + HHb) during each venous occlusion. For each timepoint, the average muscle blood flow from three occlusions was retained for data analysis.

Blood Analyses. Blood samples were drawn at the baseline, 1-h post, 5-h post, and 24-h post time points via venepuncture (Winged Infusion Set 21G x 0.75", Smiths Medical, USA). Two blood samples of approximately 10 mL each were collected into an EDTA tube (Smiths Medical, USA), and a portion (100 µL) of blood was analysed immediately for total haemoglobin (KX-21 N Sysmex, Japan; subsequently used for muscle blood flow analysis), blood glucose, and lactate concentrations (YSI 2500 Glucose/Lactate Analyser).

One Repetition Max Testing. During Visit 1, participants were assessed for their 1RM leg press to prescribe an appropriate load for their exercise intervention during Visit 2. This testing commenced with a standardised warm-up consisting of 5-min cycling at 1 Watt (W) per kg body mass, 10 repetitions of bodyweight squats, 10 repetitions of bodyweight walking lunges on each leg, high knee runs over 20 m, heel kick runs over 20 m, 10 Romanian deadlifts with a dowel, 2 submaximal CMJs at 50% and 75% perceived effort, and 1 maximal CMJ. Following the warm-up, participants completed a total of three warm-up sets on the leg press machine (Hammer Strength Linear, Schiller Park, IL, USA), consisting of 10 reps with no weight, 5 reps at 50% of self-estimated 1RM, and 2-3 reps at 75% estimated 1RM (38). Participants then performed one leg press repetition at an estimated 90% of 1RM. If this repetition was completed successfully, and with correct technique, participants performed another one-repetition effort with gradually increasing resistance until failure or loss of technique. A 3-min rest period was used between maximum effort attempts. A successful 1RM was classified as the greatest mass lifted with correct form through a complete range of motion, i.e., the participant's maximum possible knee extension and knee flexion positioned in the leg press machine (39).

Exercise Performance Testing. Prior to performance testing, participants performed the same standardised warm-up as completed before 1RM testing. Following the warm-up, participants performed three maximal, non-continuous, unloaded CMJs on a 400 × 600 mm force platform (Kistler; Winterthur, Switzerland), with 10-s of rest between jumps. CMJs were performed with hands on hips to eliminate the influence of an arm swing. Participants were instructed to choose a self-selected squat depth and to jump for maximum height. Raw force-time data was obtained from the force platform software and analysed using Quattro Jump software (Kistler; Winterthur, Switzerland). The average CMJ height (in m, from take-off velocity), Reactive Strength Index modified (RSI-mod) (in m/s, calculated as jump height divided by jump time), push off time (s) and push off force impulse (N·s) were calculated for each timepoint. These metrics were selected as they represent key aspects of the CMJ, including the timing (push off time) and magnitude (push off force impulse) of force application, in addition to the resultant output (CMJ height). Given that measures scaled to jump output are most sensitive to neuromuscular fatigue (40), RSI-mod was also included as a measure of interest.

The IMTP assessment was performed using an immovable bar placed within a squat rack, while standing on the same force platform (Kistler; Winterthur, Switzerland). The bar was adjusted to be in contact with the upper part of the thigh, below the hip crease, and participants subsequently positioned their knees and hips at angles which replicated the second pull position of the power clean. Individual barbell height, hip and knee angles were replicated at each IMTP timepoint. With lifting straps applied to their wrists, participants were cued with the phrase ‘push into the platform as hard and fast as possible’ and instructed to maintain grip on the barbell for 3 s. Participants first performed two warm-up repetitions at 50% perceived effort and 75% perceived effort. Two maximal repetitions were then performed separated by 2-min rest, with a third repetition performed if a difference of > 250 N was observed between absolute peak forces of the first two efforts. The force-time curve was visually inspected to ensure a stable weighing period and no countermovement for each repetition. Raw force-time data was obtained from the force platform software and analysed using ForceDecks software (VALD Performance, Newstead, Australia). The average net force at 100 ms (N), net force at 200 ms (N), and net peak vertical force (N) were calculated for each timepoint. These metrics were selected for analysis as they represent both rapid force production (net force at 100 and 200ms) and maximal isometric strength (41).

Perceptual Measures. Ratings of perceived muscle soreness (MS) for the legs were obtained on a visual analogue scale of one (no soreness) to ten (maximal soreness) (Thompson et al., 1999), while participants self-palpated the gluteal, hamstring and thigh muscles. Ratings of perceived recovery and fatigue were assessed using the Total Quality of Recovery (TQR) scale, which is a scale from 6 (no recovery) to 20 (maximal recovery) (42). Additionally, a subjective wellbeing survey (SWS) was completed at baseline (Visit 2) and 24-h post exercise (Visit 3). This survey recorded participant’s perception of fatigue, sleep quality, general muscle soreness, stress and mood, each on a five-point scale (Mclean et al., 2010). The combined total score of the five categories was used to calculate an overall wellbeing score (best positive result = 25).

Exercise Intervention. An eccentric-focused lower body exercise intervention was used to promote muscle damage, as used previously by O'Riordan, Bishop (14). Participants were seated on a leg press machine and placed their feet shoulder-width apart and flat on the platform. Following two warm-up sets (10 unloaded reps; 8 reps at 50% 1RM), participants completed 8 sets of 6 repetitions of a leg press exercise at 85% of their 1RM. Each repetition was monitored by the investigator to ensure that participants lowered the resistance platform slowly for a duration of 4-s before pushing the platform back to its starting position as quickly as possible. A 3-minute rest period was maintained between each set.

Recovery Intervention. For both recovery interventions (COMP or CON), participants were seated on a laboratory bed with legs supine for 5 h post-exercise. Participants in the CON group did not receive any recovery intervention but remained supine for 5-h post-exercise. For the COMP recovery intervention, full-length (waist-to-ankle) compression tights (Pressio Inc, London, United Kingdom) were provided immediately after post-exercise testing and worn for the duration of the 5-h recovery period only. To facilitate the 1-h post-exercise measures, the tights were briefly rolled down to the mid-thigh to allow for placement of the NIRS oximeter and preparation of the muscle biopsy site and then returned to position. The oximeter was removed after the blood flow measurement and the tights were briefly rolled down once more for the biopsy procedure before being returned to their normal position for the remainder of the recovery period. Manufacturer guidelines were used to provide an approximate guide for sizing of compression tights. The applied interface pressure of the compression garments was assessed during Visit 1 at six standard anthropometric sites on the participant's right leg (Figure 2), in both standing and supine positions. Garment pressure was measured using a Kikuhime pressure monitor (MediGroup, Melbourne, Australia), which has previously been shown to be both valid and reliable (43). From landmark A (upper ankle) to F (upper thigh), the average applied garment pressure (mmHg) of the sports compression tights in COMP was 12.2 ± 2.8 (A), 13.0 ± 3.1 (B), 18.9 ± 4.6 (C), 9.1 ± 2.1 (D), 8.3 ± 1.8 (E) and 6.7 ± 1.4 (F), measured in the supine position.

Dietary & Exercise Controls. Participant meals were standardised for the evening meal prior to Visit 2, the lunch meal during Visit 2, and the evening meal prior to Visit 3. Meals were individually prescribed based on a fixed macronutrient proportion of 55% carbohydrates, 20% protein and 25% fat content per meal, relative to participant body mass (44). The standardised meals were provided as commercially available meals (Dineamic; Melbourne, Australia) with additional snacks (e.g., fruit juice, muesli bars) included as required to meet the individual macronutrient targets. Following the exercise intervention in Visit 2, participants were provided with a shake made with water and protein powder (Lean WPI, Genetix Nutrition) equating to 0.3 g of protein per kilogram of body mass (45, 46). All participants completed a 24-h food diary prior to Visit 2 to encourage replication of diet between Visit 2 and Visit 3 (inclusive of the provided meal).

Participants were asked to refrain from caffeine and alcohol consumption (< 12-h) before Visit 2 and Visit 3. Participants presented to the laboratory for Visit 2 and Visit 3 following a minimum 8-h fasting period. In addition, participants were asked to refrain from unaccustomed exercise for 7 days prior to Visit 2, and to refrain from all exercise for 24 h preceding Visit 2. Participants were also asked to refrain from other exercise and recovery interventions between Visit 2 and Visit 3.

Statistical Analyses

Descriptive statistics (means and standard deviations) for all variables were computed for each time point. A repeated measures ANOVA was conducted to assess differences in subjective wellbeing (total SWS score) between groups using a 2x2, Group (COMP and CON) x Time (baseline and 24-h post) design. Data were assessed for normality via Normal Q-Q Plots and examination of studentized residuals for values greater than ± 3.

For all other variables, a linear mixed model (LMM) was fit with a fixed effect for time (categorical factor: 4-5 levels), interacted with condition (categorical factor, 2 levels: COMP, CON). A random intercept and slope model was first fit to allow a different variance over time per group. However, the model failed to converge, hence the random effect structure was simplified to a random intercept (by ID) only model. Time varying variance was modelled using an autoregressive lag 1 (AR1) covariance structure. Marginal and conditional R^2 values were calculated to estimate the fit of the model fixed effects (marginal R^2) and fixed and random effects (conditional R^2) (47). The assumption of normality of model residual was examined via visual inspection of Q-Q plots and an appropriate transformation applied to stabilise the variance if this assumption was violated. The imprecision of model fixed effect parameter estimate was denoted by 95% bootstrapped confidence interval (1000 iterations). All statistical analyses were conducted using Jamovi (Version 2.5.6) at the 95% level of significance ($p < 0.05$).

RESULTS

Protein content

Representative western blot images for total protein content and phosphorylated protein content are shown in Figure 3. There were no interaction effects for total mTOR protein [F(3, 43)

= 0.09, $p = 0.967$], total p70S6K protein [$F(3, 53) = 0.575$, $p = 0.634$], total 4E-BP1 protein [$F(3, 54) = 0.901$, $p = 0.447$], total rps6 protein [$F(3, 54) = 1.07$, $p = 0.370$] or total eF2 protein [$F(3, 52) = 0.08$, $p = 0.972$]. Additionally, there were no interaction effects for mTOR activation ratio [$F(3, 14) = 0.58$, $p = 0.626$], p70S6K ratio [$F(3, 29) = 0.21$, $p = 0.892$], 4E-BP1 activation ratio [$F(3, 42) = 0.742$, $p = 0.533$], rps6 activation ratio [$F(3, 42) = 0.49$, $p = 0.693$], or eF2 activation ratio [$F(3, 49) = 1.292$, $p = 0.288$].

There were main effects of time for total mTOR protein [$F(3, 43) = 5.07$, $p = 0.004$], total p70S6K protein [$F(3, 54) = 3.95$, $p = 0.013$], total 4E-BP1 protein [$F(3, 54) = 4.60$, $p = 0.006$], total rps6 protein [$F(3, 54) = 9.55$, $p < 0.001$] and total eF2 protein [$F(3, 52) = 10.14$, $p < 0.001$]. Post-hoc analyses revealed lower total mTOR, p70S6K, rps6 and e-F2 protein content at 1-h post and 5-h post compared to baseline, and lower total 4E-BP1 protein at 1-h post compared to baseline.

There was also a main effect of time for mTOR ratio [$F(3, 14) = 16.66$, $p < 0.001$], p706SK ratio [$F(3, 29) = 25.22$, $p < 0.001$], 4E-BP1 ratio [$F(3, 42) = 8.694$, $p < 0.001$], rps6 ratio [$F(3, 42) = 77.40$, $p < 0.001$]. Post-hoc analyses revealed a greater total mTOR ratio and 4E-BP1 ratio at 1-h post and 5-h post compared to baseline, and greater p706SK ratio and rps6 ratio at 1-h post, 5-h post and 24-h post compared to baseline (Figure 4).

No interaction effects were observed for muscle blood flow [$F(3, 47) = 0.25$, $p = 0.86$], blood lactate [$F(3, 53) = 0.536$, $p = 0.66$], blood glucose [$F(3, 54) = 0.235$, $p = 0.87$], MS [$F(4, 72) = 0.586$, $p = 0.67$], TQR [$F(4, 72) = 2.02$, $p = 0.10$], or SWS total score [$F(1, 18) = 3.10$, $p = 0.10$].

There were main effects of time for muscle blood flow [$F(3, 47) = 6.28$, $p = 0.01$], blood lactate [$F(3, 53) = 0.536$, $p < 0.001$), blood glucose [$F(3, 54) = 7.59$, $p < 0.001$), MS [$F(4, 72) = 19.10$, $p < 0.001$], TQR [$F(4, 72) = 16.09$, $p < 0.001$] and SWS total score [$F(1, 18) = 3.10$, $p =$

0.01]. Post-hoc analyses revealed greater muscle blood flow (0.03 ± 0.01 mL/min·100/g, $p <$ 0.001), greater blood lactate (0.186 ± -0.08 mmol/L, $p < 0.001$) and lower blood glucose (-0.61 ± 0.30 mmol/L, $p < 0.001$) at 1-h post compared to baseline in both groups. MS was greater at each timepoint compared to baseline (post-exercise: 2.3 ± 0.94 AU, $p < 0.001$; 1-h post: 1.65 ± 0.67 AU, $p < 0.001$; 5-h post: 1.5 ± 0.22 AU, $p = 0.003$; 24-h post: 3.1 ± 0.98 AU, $p < 0.001$), while TQR was lower at each timepoint compared to baseline (post-exercise: -4.0 ± 0.46 AU, $p = 0.001$; 1-h post: -2.2 ± 0.05 AU, $p < 0.001$; 5-h post: -2.0 ± 0.03 AU, $p = 0.001$; 24-h post: -2.3 ± 0.5 AU, $p < 0.001$) for both groups. Additionally, SWS total score was lower at 24-h compared to baseline (-1.7 ± 0.62 AU, $p = 0.01$) for both groups (Table 3).

There were no interaction effects for CMJ height [F(3, 54) = 1.46, $p = 0.236$], CMJ RSI-mod [F(3, 53) = 2.75, $p = 0.052$], CMJ push off time [F(3, 52) = 0.79, $p = 0.50$], CMJ push off force impulse [F(3, 52) = 2.21, $p = 0.10$], IMTP net force at 100ms [F(3, 53) = 1.38, $p = 0.26$], IMTP net force at 200ms [F(3, 53) = 1.58, $p = 0.21$] or IMTP net peak vertical force [F(3, 53) = 0.571, $p = 0.64$] There was a main effect of time for CMJ height [F(3, 54) = 3.71, $p = 0.02$], with post-hoc analyses revealing lower jump height at post-exercise (-0.03 ± 0.01 m, $p = 0.002$), 5 h post (-0.02 ± 0.02 m, $p = 0.03$) and 24 h post (-0.02 ± 0.01 m, $p = 0.02$) compared to baseline for both groups (Table 4).

DISCUSSION

The primary aim of this study was to investigate the effects of compression garments on markers of muscle protein synthesis and muscle blood flow when used for recovery post-resistance exercise. A secondary aim was to assess the effect of compression garments on the recovery of physical performance and perceptual recovery characteristics. The main findings were that the commercially available compression garments used in the present study were not associated with any beneficial effects when worn for 5 h following resistance exercise. In particular there were no changes in markers of muscle protein synthesis or muscle blood flow following resistance exercise, and no effect of the garments on physical performance or perceived recovery over a 24-h follow-up period.

A novel component of this study was to investigate the effects of wearing compression garments post-exercise on markers of muscle protein synthesis, a first in the field of compression garment research. Our findings showed that there was no significant effect of compression garments on markers of muscle protein synthesis when used for recovery following resistance exercise. Overall, the results demonstrate normal temporal changes in key signalling proteins in both groups, including increased phosphorylation of mTOR and 4E-BP1 for 5 h, and a sustained increase in phosphorylation of p706SK and rps6 for 24 h post-exercise, indicative of their role as key downstream targets of the mTOR pathway (23). These changes are consistent with previous reports on the effects of resistance exercise on acute muscle protein responses (48-50), and are associated with skeletal muscle hypertrophy with resistance training (51). In contrast to the current findings, previous research on CWI has reported the suppression of muscle protein synthesis and skeletal muscle hypertrophy alongside increased markers of protein degradation (28, 30). While this has placed CWI largely in the category of a 'hormetic agent' (52) that should be used with caution in the context of resistance exercise recovery, the current data does not indicate that compression garments have any significant effect on markers of muscle protein synthesis. However, as markers of muscle protein degradation and measures of muscle protein synthesis were not analysed in the present study, the potential effect of compression garments on overall muscle protein balance cannot be inferred, and this may be of interest in future research.

A potential explanation for the observed lack of change in markers of muscle protein synthesis with compression garments may be the absence of compression-induced increases in muscle blood flow, which was expected based on previous research (14, 37, 53). However, it is notable that such studies have used compression garments exerting a higher applied pressure than those in the current study, particularly at the thigh (~15 mmHg compared to 8 mmHg), which may explain the lack of changes in muscle blood flow. This underlines the inherent variability of commercially available compression garments, which, due to fabric type, composition, garment sizing, and anthropometry can result in differences in the magnitude of applied pressure on individuals. For instance, significant differences in applied pressure have been observed between three commercially available brands of sports compression tights measured in the same participant group (18). In the current study, manufacturer guidelines were used only as an approximate guide for sizing of the compression garments, with greater consideration given to the pressure applied across the leg, as recommended by MacRae, Laing (54). Despite this, garment pressure was still lower than reported in previous studies using commercially available sports compression tights (14, 18). While there is no consensus on a 'minimum dose' of pressure for compression garments to be effective, higher-pressure compression garments may improve physical and perceptual recovery after a damaging drop jump protocol to a greater degree than low-pressure compression garments (thigh: 14.8 ± 2.2 mmHg vs 8.1 ± 1.3 mmHg) (6). As such, the relatively low pressure of the compression garments (mid-thigh: 8.3 ± 1.8 mmHg) used in the current study was clearly a limiting factor that likely contributed to the lack of change in muscle blood flow. Alternatively, it is also possible that a divergent effect of compression garments on blood flow occurred, whereby femoral blood flow was altered with compression garments, but no change was apparent at the microvascular (muscle) level (15). However, without direct measurement of femoral blood flow in the present study, this is purely speculative.

Given that muscle blood flow is associated with glucose uptake (55), the lack of change in muscle blood flow observed may also explain the absence of any effect on blood glucose with the use of compression garments for recovery. A normal post-exercise blood glucose response was observed across both groups (56), whereby blood glucose significantly decreased at 1-h post-exercise compared to baseline. Only one previous investigation in compression garments has reported on glucose uptake, finding no difference with the use of compression shorts after high-intensity cycling (57). However, it is difficult to compare to this study, given that the applied pressure of the compression shorts (~37 mmHg) was substantially higher than the compression tights used in the present study. As such, it is not clear whether blood glucose or glucose uptake is unchanged with compression garments, or if it is dependent on garment pressure and, subsequently, muscle blood flow. Similarly, while blood lactate was significantly increased at 1-h post-exercise compared to baseline, there was no difference between groups. This may reflect the difficulty of using blood markers as an indicator of physiological recovery, which contributes to the variable findings on the effect of compression garments on lactate responses after exercise (58). However, it is also probable that there was a mixed response to the exercise intervention across the participant group due to the training status and sex of the participants (59, 60), which influences the interpretation of these blood measures.

Compression garments used for 5 h post-resistance exercise did not influence the recovery of physical performance, as assessed through CMJ and IMTP testing. This aligns with previous studies investigating the use of compression garments for recovery after resistance exercise, which have generally reported no improvement in CMJ metrics (9, 10, 27). Similarly, the lack of effect of compression garments on IMTP performance is in agreement with previous research demonstrating no significant changes to IMTP absolute or relative peak force with post-resistance exercise compression garment use (14). While the 5-h recovery period used in the present study reflects the most common duration that athletes wear compression garments after exercise (61), longer periods of compression wear (> 12-h) are often associated with improvements in jump performance and recovery of muscle strength after resistance exercise (4, 8). This suggests that further research into the dose-response relationship for compression garments may be required to understand the potential effects of different garment wear periods on the recovery of physical performance.

A common consideration in recovery research is whether the exercise intervention implemented was of an appropriate intensity for participants, thereby warranting the use of a recovery intervention. The leg press exercise session which was implemented was clearly strenuous from both a physical and perceptual perspective, as demonstrated by a significant reduction in CMJ height immediately following exercise and increased blood lactate and decreased blood glucose at 1-h post-exercise in both groups. Additionally, all perceptual measures (MS, TQR and SWS) were significantly impaired during the 24-h follow-up period in both groups. These post-exercise physical and perceptual responses were of a similar magnitude to previous studies of recovery interventions which utilised resistance or eccentric-based exercise interventions to maximise muscle damage ((6, 10, 62).Further, the changes to muscle protein synthesis signalling pathways in both groups were consistent with the response to a resistance exercise session (22, 23). This highlights that the exercise intervention was of an appropriate intensity and resulted in reduced indices of perceived recovery, with no apparent difference with the use of compression garments post-exercise. In contrast, compression garment research often presents a positive effect of compression garments use post-exercise on measures of perceived soreness, pain, recovery and comfort (4, 63, 64). It is possible that there was a varied response to the exercise intervention across and within groups as a result of individual factors (e.g., training status), which subsequently may have influenced subjective wellbeing and perceived recovery quality. Indeed, there was a clear difference in TQR from baseline to post-exercise in COMP compared to CON, despite no recovery intervention having been delivered at this timepoint, demonstrating a distinct response to the exercise intervention in this group. While a parallel group design, such as that in the present study, can overcome the potential confounder of a repeated bout effect (65), a crossover design study also has its advantages (i.e., reducing between-subject variability), though it is often not feasible due to logistical constraints.

CONCLUSIONS

In conclusion, results from the present study suggest that commercially available compression tights used for 5-h following a lower-body resistance exercise session were not associated with changes in markers of muscle protein synthesis, which may be due to a lack of change in muscle blood flow. Although previous research supports the benefits of compression garments used after resistance exercise, the current study did not observe any compression-induced benefits on indices of exercise recovery (i.e., performance, perceptual, blood markers). Overall, this study provides novel insight into molecular responses when using commercially available compression garments after resistance exercise and should be considered a starting point for future research interested in understanding adaptive responses to post-exercise compression garment use. Higher compression garment pressure than observed in this study may be required to observe any compression-induced physiological effects. Additionally, it may be useful to investigate muscle protein synthesis via amino acid tracers, as well as analyse acute changes in muscle protein degradation markers, to improve the understanding of changes in overall muscle protein balance with the use of compression garments for recovery after resistance exercise.

REFERENCES

1. Kraemer WJ, Ratamess NA, French DN. Resistance training for health and performance. *Curr Sports Med Rep.* 2002;1(13):165-71.

2. Schoenfeld BJ, Contreras B. Is postexercise muscle soreness a valid indicator of muscular adaptations? *Strength Cond J.* 2013;35(5):16-21.

3. Mayberry JC, Moneta GL, De Frang RD, Porter JM. The influence of elastic compression stockings on deep venous hemodynamics. *J Vasc Sug.* 1991;13(1):91-100.

4. Goto K, Morishima T. Compression garment promotes muscular strength recovery after resistance exercise. *Med Sci Sports Exerc.* 2014;46(12):2265-70.

5. Shimokochi Y, Kuwano S, Yamaguchi T, Abutani H, Shima N. Effects of wearing a compression garment during night sleep on recovery from high-intensity eccentric-concentric quadriceps muscle fatigue. *J Strength Cond Res*. 2017;31(10):2816-24.

6. Hill J, Howatson G, van Someren K, et al. The effects of compression-garment pressure on recovery after strenuous exercise. *Int J Sports Physiol Perform.* 2017;12(8):1078-84.

7. Hettchen M, Glöckler K, von Stengel S, et al. Effects of compression tights on recovery parameters after exercise induced muscle damage: a randomized controlled crossover study. *Evid Based Complement Alternat Med.* 2019;2019:5698460.

8. Jakeman JR, Byrne C, Eston RG. Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *Eur J Appl Physiol.* 2010;109(6):1137-44.

9. French DN, Thompson KG, Garland SW, et al. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sports Exerc.* 2008;40(7):1297-306.

10. Kraemer WJ, Flanagan SD, Comstock BA, et al. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *J Strength Cond Res.* 2010;24(3):804-14.

11. Davies V, Thompson KG, Cooper SM. The effects of compression garments on recovery. *J Strength Cond Res.* 2009;23(6):1786-94.

12. de Glanville KM, Hamlin MJ. Positive effect of lower body compression garments on subsequent 40-kM cycling time trial performance. *J Strength Cond Res.* 2012;26(2):480-6.

13. Zinner C, Pelka M, Ferrauti A, Meyer T, Pfeiffer M, Sperlich B. Responses of low and high compression during recovery after repeated sprint training in well-trained handball players. *Eur J Sport Sci.* 2017;17(10):1304-10.

14. O'Riordan SF, Bishop DJ, Halson SL, Broatch JR. Compression-induced improvements in post-exercise recovery are associated with enhanced blood flow, and are not due to the placebo effect. *Sci Rep.* 2022;12(1):16762.

15. Broatch JR, O'Riordan SF, Keske MA, et al. Reduced post-exercise muscle microvascular perfusion with compression is offset by increased muscle oxygen extraction: assessment by contrast-enhanced ultrasound. *FASEB J.* 2021;35(5):e21499.

16. Book J, Prince C, Villar R, et al. Investigating the impact of passive external lower limb compression on central and peripheral hemodynamics during exercise. *Eur J Appl Physiol.* 2016;116(4):717-27.

17. Sperlich B, Haegele M, Krüger M, Schiffer T, Holmberg HC, Mester J. Cardio-respiratory and metabolic responses to different levels of compression during submaximal exercise. *Phlebology*. 2011;26(3):102-6.

18. Broatch JR, Brophy-Williams N, Phillips EJ, et al. Compression garments reduce muscle movement and activation during submaximal running. *Med Sci Sports Exerc.* 2020;52(3):685-95.

19. Hill J, Howatson G, Someren K, Davidson S, Pedlar C. The variation in pressures exerted by commercially available compression garments. *Sports Eng.* 2015;18(2):115-21.

20. Biolo G, Tipton KD, Klein S, Wolfe RR. An abundant supply of amino acids enhances the metabolic effect of exercise on muscle protein. *Am J Physiol Endocrinol Metab.* 1997;273(1):E122-9.

21. Fujita S, Rasmussen BB, Cadenas JG, Grady JJ, Volpi E. Effect of insulin on human skeletal muscle protein synthesis is modulated by insulin-induced changes in muscle blood flow and amino acid availability. *Am J Physiol Endocrinol Metab.* 2006;291(4):E745-54.

22. MacDougall JD, Gibala MJ, Tarnopolsky MA, MacDonald JR, Interisano SA, Yarasheski KE. The time course for elevated muscle protein synthesis following heavy resistance exercise. *Can J Appl Physiol.* 1995;20(4):480-6.

23. Terzis G, Georgiadis G, Stratakos G, et al. Resistance exercise-induced increase in muscle mass correlates with p70S6 kinase phosphorylation in human subjects. *Eur J Appl Physiol.* 2008;102:145-52.

24. Phillips SM, Tipton KD, Aarsland A, Wolf SE, Wolfe RR. Mixed muscle protein synthesis and breakdown after resistance exercise in humans. *Am J Physiol Endocrinol Metab.* 1997;273(1):E99-107.

25. Eliasson J, Elfegoun T, Nilsson J, Kohnke R, Ekblom Br, Blomstrand E. Maximal lengthening contractions increase p70 S6 kinase phosphorylation in human skeletal muscle in the absence of nutritional supply. *Am J Physiol Endocrinol Metab.* 2006;291(6):E1197-205.

26. Karlsson HK, Nilsson P-A, Nilsson J, Chibalin AV, Zierath JR, Blomstrand E. Branched-chain amino acids increase p70S6k phosphorylation in human skeletal muscle after resistance exercise. *Am J Physiol Endocrinol Metab.* 2004;287(1):E1-7.

27. Goto K, Mizuno S, Mori A. Efficacy of wearing compression garments during post-exercise period after two repeated bouts of strenuous exercise: a randomized crossover design in healthy, active males. *Sports Med Open.* 2017;3(1):25.

28. Fyfe JJ, Broatch JR, Trewin AJ, et al. Cold water immersion attenuates anabolic signaling and skeletal muscle fiber hypertrophy, but not strength gain, following whole-body resistance training. *J Appl Physiol (1985).* 2019;127(5):1403-18.

29. Fuchs CJ, Kouw IW, Churchward-Venne TA, Smeets JS, Senden JM, Lichtenbelt WDvM, et al. Postexercise cooling impairs muscle protein synthesis rates in recreational athletes. *J Physiol.* 2020;598(4):755-72.

30. Roberts LA, Raastad T, Markworth JF=, et al. Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. *J Physiol.* 2015;593(18):4285-301.

31. Kakigi R, Naito H, Ogura Y, et al. Heat stress enhances mTOR signaling after resistance exercise in human skeletal muscle. *J Physiol Sci.* 2011;61(2):131-40.

32. Fuchs CJ, Smeets JS, Senden JM, et al. Hot-water immersion does not increase postprandial muscle protein synthesis rates during recovery from resistance-type exercise in healthy, young males. *J Appl Physiol (1985).* 2020;128(4):1012-22.

33. Leicht CA, James LJ, Briscoe JH, Hoekstra SP. Hot water immersion acutely increases postprandial glucose concentrations. *Physiol Rep.* 2019;7(20):e14223.

34. Elliott-Sale KJ, Minahan CL, de Jonge XAJ, et al. Methodological considerations for studies in sport and exercise science with women as participants: a working guide for standards of practice for research on women. *Sports Med.* 2021;51(5):843-61.

35. Shanely RA, Zwetsloot KA, Triplett NT, Meaney MP, Farris GE, Nieman DC. Human skeletal muscle biopsy procedures using the modified Bergström technique. *J Vis Exp.* 2014(91):51812.

36. Tarnopolsky MA, Pearce E, Smith K, Lach B. Suction-modified Bergström muscle biopsy technique: experience with 13,500 procedures. *Muscle Nerve.* 2011;43(5):716-25.

37. Broatch JR, Bishop DJ, Halson S. Lower limb sports compression garments improve muscle blood flow and exercise performance during repeated-sprint cycling. *Int J Sports Physiol Perform.* 2018;13(7):882-90.

38. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, Sonmez GT. Effects of low-vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. *J Strength Cond Res.* 2015;29(10):2954-63.

39. Baechle TR, Earle RW. Essentials of strength training and conditioning: Human kinetics. National Strength & Conditioning Association. 2008.

40. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of elite players to an Australian rules football match. *Int J Sports Physiol Perform.* 2008;3(3):359-74.

41. James LP, Talpey SW, Young WB, Geneau MC, Newton RU, Gastin PB. Strength classification and diagnosis: not all strength is created equal. *Strength Cond J.* 2023;45(3):333-41.

42. Kentta G, Hassmen P. Overtraining and recovery. A conceptual model. *Sports Med.* 1998;26:1-16.

43. Brophy-Williams N, Driller M, Halson S, Fell J, Shing C. Evaluating the Kikuhime pressure monitor for use with sports compression clothing. *Sports Eng.* 2014;17(1):55-60.

44. Thomas DT, Erdman KA, Burke LM. Nutrition and athletic performance. *Med Sci Sports Exerc.* 2016;48(3):543-68.

45. Morton RW, McGlory C, Phillips SM. Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy. *Front Physiol.* 2015;6:245.

46. Moore DR. Maximizing post-exercise anabolism: the case for relative protein intakes. *Front Nutr.* 2019;6:485822.

47. Nakagawa S, Schielzeth H. A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods Ecol Evol. 2013;4(2):133-42.

48. Dreyer HC, Fujita S, Cadenas JG, Chinkes DL, Volpi E, Rasmussen BB. Resistance exercise increases AMPK activity and reduces 4E-BP1 phosphorylation and protein synthesis in human skeletal muscle. *J Physiol.* 2006;576(2):613-24.

49. Bolster DR, Kubica N, Crozier SJ, et al. Immediate response of mammalian target of rapamycin (mTOR)-mediated signalling following acute resistance exercise in rat skeletal muscle. *J Physiol.* 2003;553(1):213-20.

50. Koopman R, Zorenc AH, Gransier RJ, Cameron-Smith D, van Loon LJ. Increase in S6K1 phosphorylation in human skeletal muscle following resistance exercise occurs mainly in type II muscle fibers. *Am J Physiol Endocrinol Metab.* 2006;290(6):E1245-52.

51. Baar K, Esser K. Phosphorylation of p70S6kcorrelates with increased skeletal muscle mass following resistance exercise. *Am J Physiol Cell Physiol.* 1999;276(1):C120-7.

52. Peake JM, Markworth JF, Nosaka K, Raastad T, Wadley GD, Coffey VG. Modulating exercise-induced hormesis: does less equal more? *J Appl Physiol (1985).* 2015;119(3):172-89.

53. O'Riordan SF, McGregor R, Halson SL, Bishop DJ, Broatch JR. Sports compression garments improve resting markers of venous return and muscle blood flow in male basketball players. *J Sport Health Sci*. 2023;12(4):513-22.

54. MacRae BA, Laing RM, Partsch H. General considerations for compression garments in sports: Applied pressures and body coverage. Compression garments in sports: Athletic performance and recovery: Springer; 2016. p. 1-32.

55. Ebeling P, Bourey R, Koranyi L, et al. Mechanism of enhanced insulin sensitivity in athletes. Increased blood flow, muscle glucose transport protein (GLUT-4) concentration, and glycogen synthase activity. *J Clin Invest.* 1993;92(4):1623-31.

56. Monroe JC, Naugle KM, Naugle KE. Effect of acute bouts of volume-matched high-intensity resistance training protocols on blood glucose levels. *J Strength Cond Res.* 2020;34(2):445-50.

57. Sperlich B, Born DP, Kaskinoro K, Kalliokoski KK, Laaksonen MS. Squeezing the muscle: compression clothing and muscle metabolism during recovery from high intensity exercise. *PLoS One.* 2013;8(4):e60923.

58. Rimaud D, Messonnier L, Castells J, Devillard X, Calmels P. Effects of compression stockings during exercise and recovery on blood lactate kinetics. *Eur J Appl Physiol.* 2010;110(2):425-33.

59. Newton MJ, Morgan GT, Sacco P, Chapman DW, Nosaka K. Comparison of responses to strenuous eccentric exercise of the elbow flexors between resistance-trained and untrained men. *J Strength Cond Res.* 2008;22(2):597-607.

60. Szivak TK, Hooper DR, Dunn-Lewis C, et al. Adrenal cortical responses to high-intensity, short rest, resistance exercise in men and women. *J Strength Cond Res.* 2013;27(3):748-60.

61. Driller MW, Brophy-Williams NN. The use of compression garments in elite Australian athletes: a survey. *J Athl Enhanc.* 2016;5:3.

62. Roberts LA, Nosaka K, Coombes JS, Peake JM. Cold water immersion enhances recovery of submaximal muscle function after resistance exercise. *Am J Physiol Regul Integr Comp Physiol.* 2014;307(8):R998-1008.

63. Atkins R, Lam WK, Scanlan AT, Beaven CM, Driller M. Lower-body compression garments worn following exercise improves perceived recovery but not subsequent performance in basketball athletes. *J Sports Sci.* 2020;38(9):961-9.

64. Brophy-Williams N, Driller MW, Kitic CM, Fell JW, Halson SL. Effect of compression socks worn between repeated maximal running bouts. *Int J Sports Physiol Perform.* 2017;12(5):621-7.

65. Nosaka K, Sakamoto K, Newton M, Sacco P. How long does the protective effect on eccentric exercise-induced muscle damage last? *Med Sci Sports Exerc.* 2001;33(9):1490-5.

FIGURE LEGENDS

Figure 1. Schematic of study design and testing measures for participant Visits 1-3. 1RM = 1 repetition maximum; CMJ = countermovement jump; COMP = compression group; CON = control group; IMTP = isometric mid-thigh pull; NIRS = near-infrared spectroscopy; MS = muscle soreness; SWS = subjective wellbeing survey; TQR = Total Quality of Recovery.

Figure 2. The following anthropometric sites were used for measuring applied garment pressure in the COMP group: A: 5 cm proximal to the distal border of the medial malleolus; B: 5 cm proximal to A; C: medial aspect of maximal calf girth; D: anterior aspect of the thigh 10 cm below landmark E; E: midpoint between the inguinal crease and the superior-posterior border of the patella; F: 5 cm proximal to landmark E.

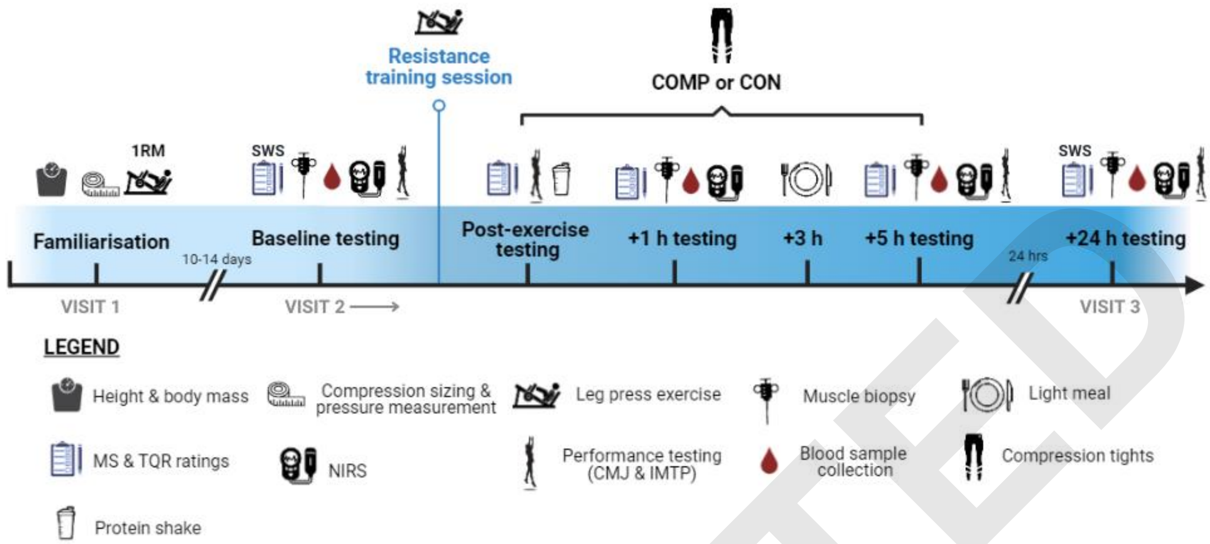
Figure 3. Representative western blot images for total protein content and phosphorylated (p) protein content at four timepoints (baseline, 1-h post-exercise, 5-h post-exercise, 24-h post-exercise) for 2 participants per group. Images have been cropped for clarity of presentation. CON = control group; COMP = compression group; 4E-BP1, eukaryotic initiation factor 4E binding protein; eF2, eukaryotic elongation factor-2; mTOR, mammalian target of rapamycin; p70S6K, p70 kDa ribosomal protein subunit kinase 1; rps6, ribosomal protein S6.

Figure 4. Ratio of activation (phosphorylated (p) protein content/total protein content) of mTOR (**A**), p70S6K (**B**), 4E-BP1 (**C)**, rps6 (**D**) and eF2 (**E**) for CON (light blue) and COMP (dark blue)

participants at four timepoints (baseline, 1-h post-exercise, 5-h post-exercise, 24-h post-exercise).

Significantly ($p < 0.05$) different from baseline for both groups.

Figure 1



Resistance training session
COMP or CON
1RM
SWS
SWS
Familiarisation
10-14 days
Baseline testing
Post-exercise testing
+1 h testing
+3 h
+5 h testing
24 hrs
+24 h testing
VISIT 1
VISIT 2
VISIT 3
LEGEND
Height & body mass
Compression sizing & pressure measurement
Leg press exercise
Muscle biopsy
Light meal
MS & TQR ratings
NIRS
Performance testing (CMJ & IMTP)
Blood sample collection
Compression tights
Protein shake

Figure 2

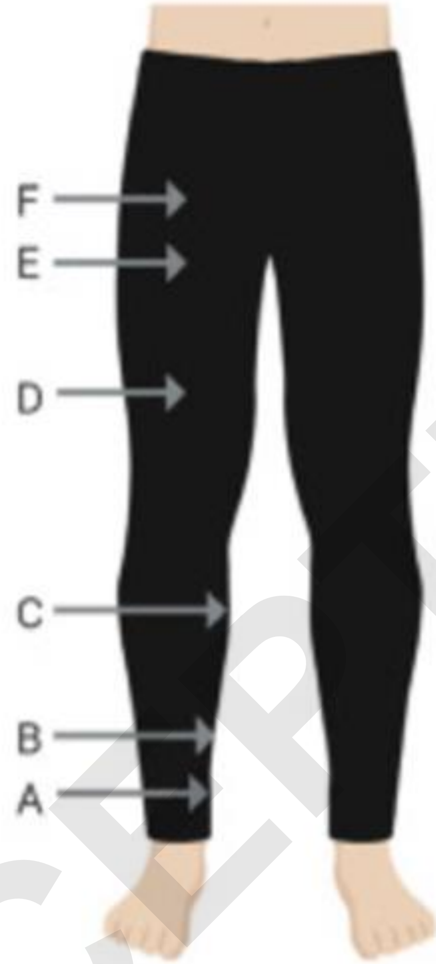


Figure 3

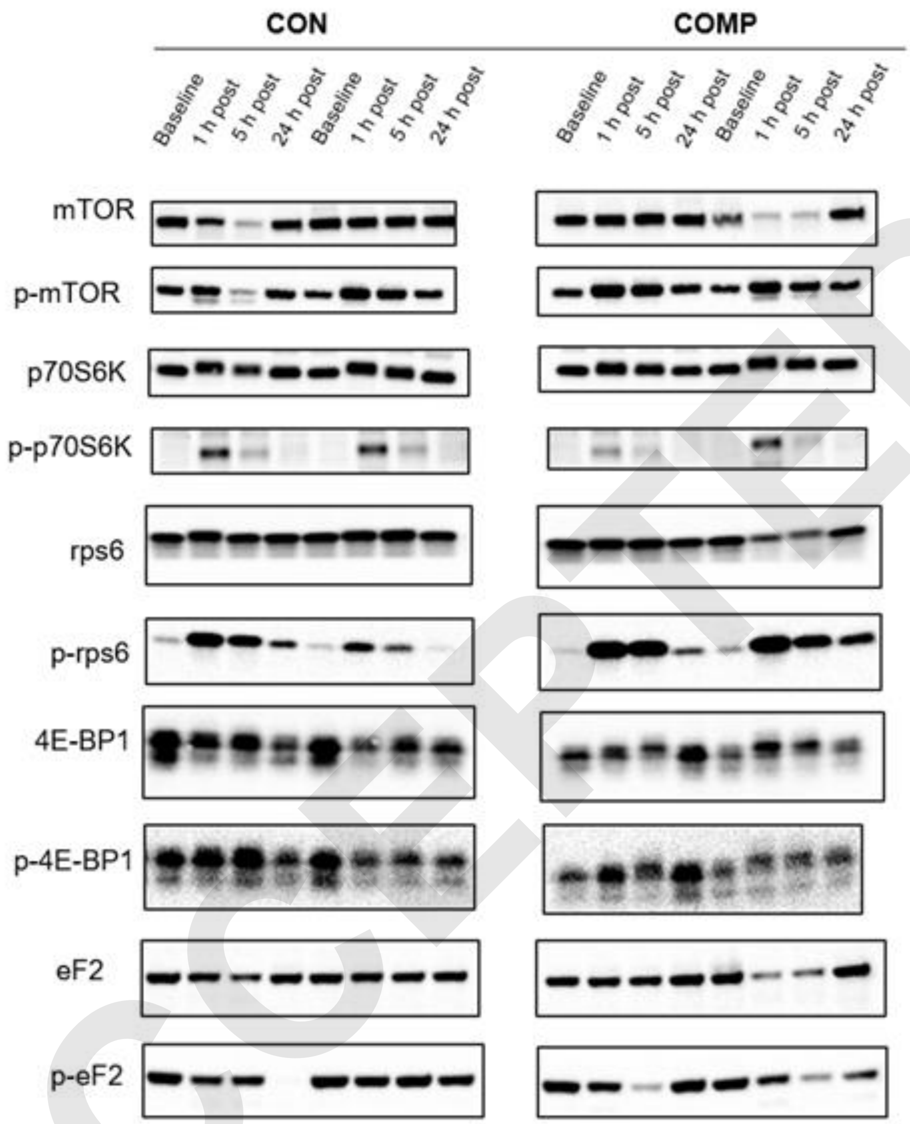

CON
COMP
Baseline
1 h post
5 h post
24 h post
Baseline
1 h post
5 h post
24 h post
Baseline
1 h post
5 h post
24 h post
Baseline
1 h post
5 h post
24 h post
mTOR
p-mTOR
p70S6K
p-p70S6K
rps6
p-rps6
4E-BP1
p-4E-BP1
eF2
p-eF2

Figure 4A

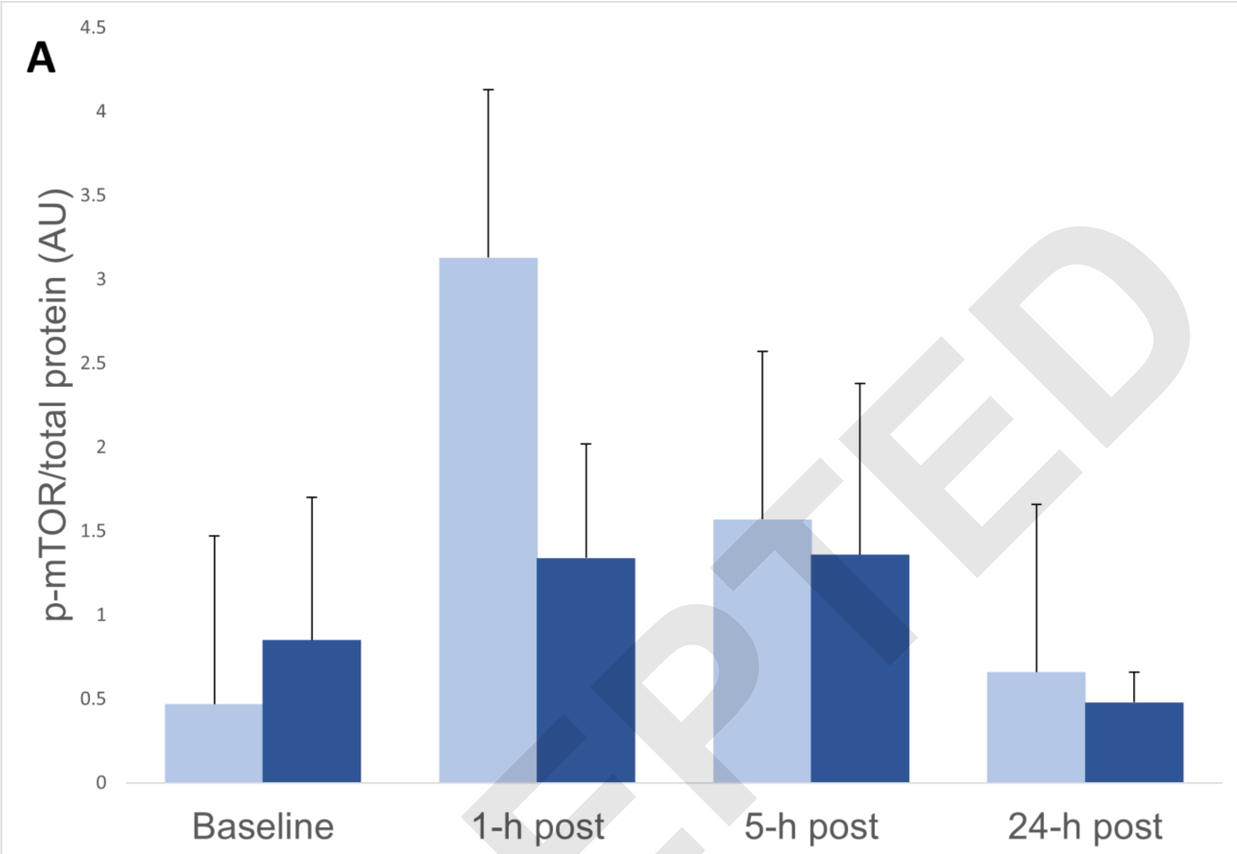
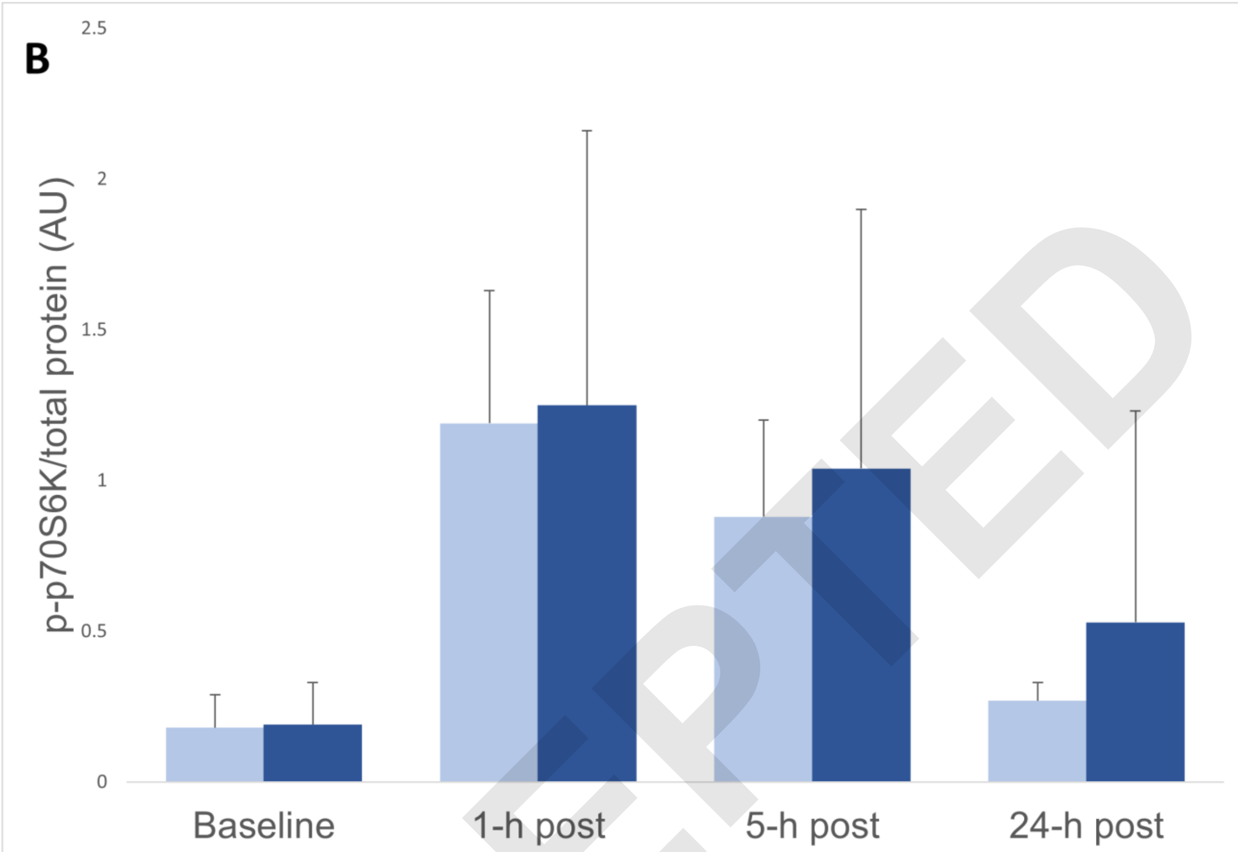

A
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
p-mTOR/total protein (AU)
Baseline
1-h post
5-h post
24-h post

Figure 4B



B
p-p70S6K/total protein (AU)
2.5
2
1.5
1
0.5
0
Baseline
1-h post
5-h post
24-h post

Figure 4C

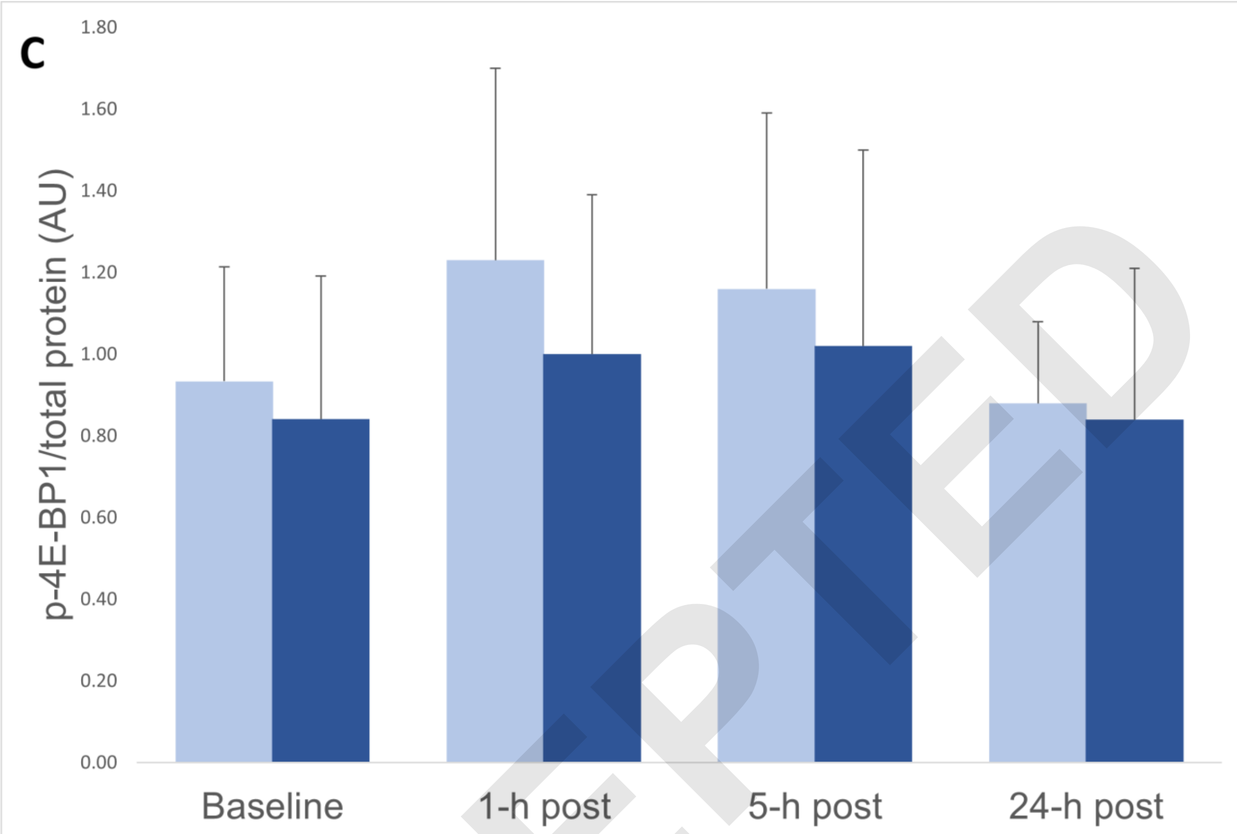

C
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
p-4E-BP1/total protein (AU)
Baseline
1-h post
5-h post
24-h post

Figure 4D

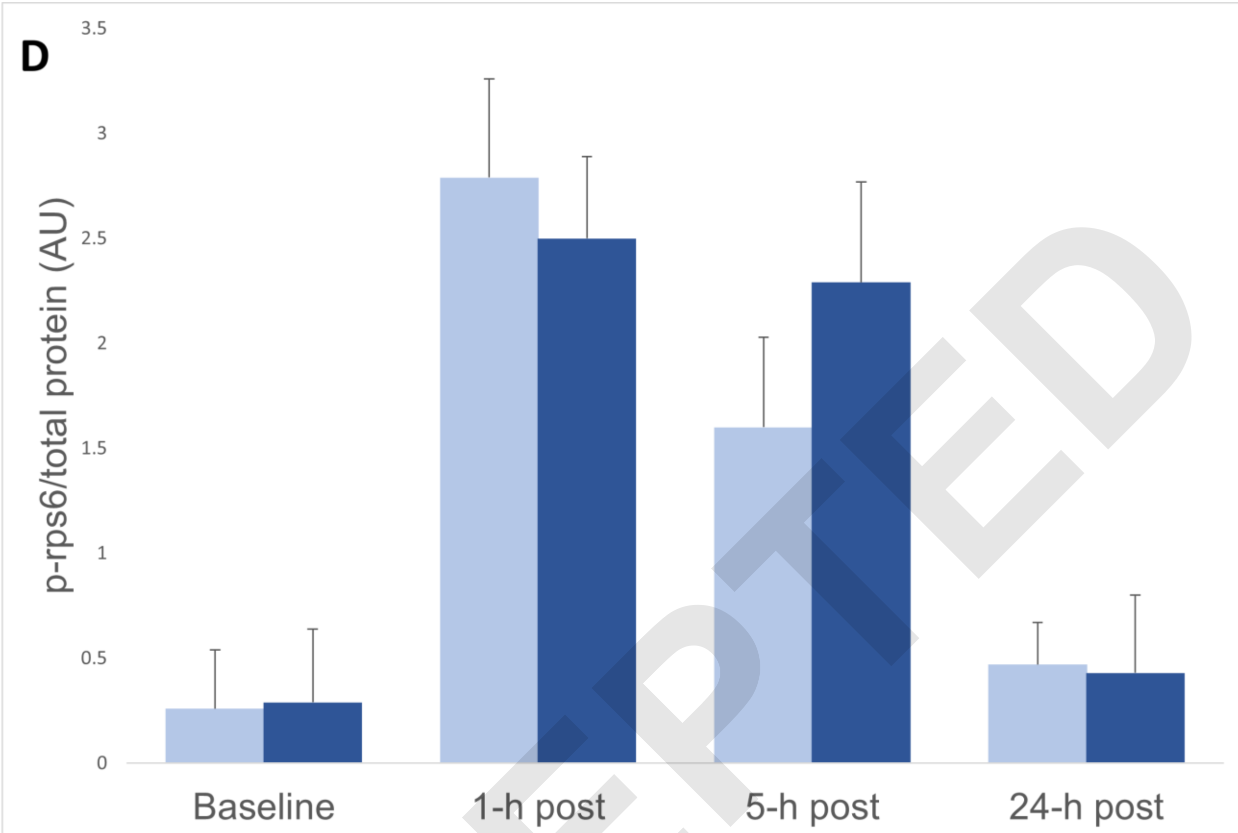
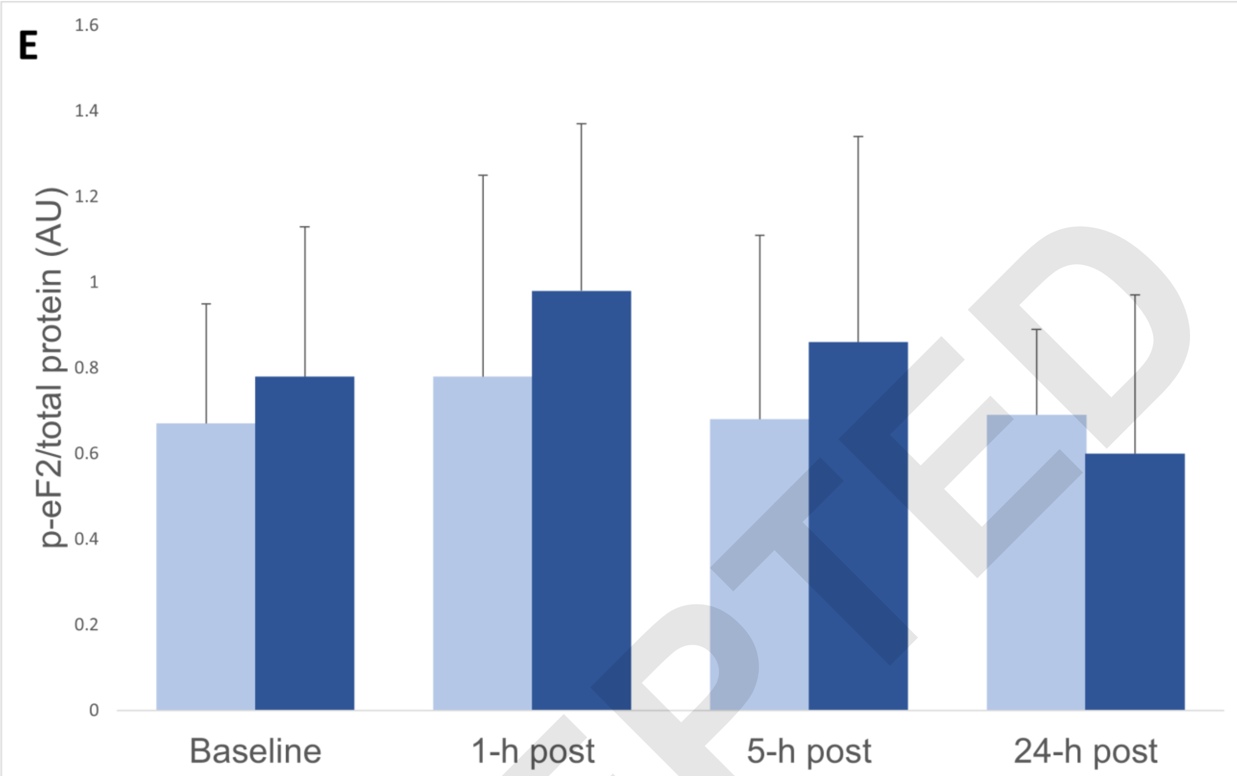

D
3.5
3
2.5
2
1.5
1
0.5
0
p-rps6/total protein (AU)
Baseline
1-h post
5-h post
24-h post

Figure 4E



E
p-eF2/total protein (AU)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Baseline
1-h post
5-h post
24-h post

Figure 4 Legend

Table 1. Descriptive characteristics of participants in control (CON) and compression (COMP) groups (mean ± SD).

	CON (n = 10)	*COMP (n = 10)*
Menstruation status of females (no. of participants)	• NM days 1-5 = 1 • NM days 6-14 = 2	• NM days 1-5 = 1 • NM days 15-21 = 1
Age (years)	28 ± 6.0	28 ± 4.0
Height (cm)	176.8 ± 12.1	171.8 ± 6.5
Body mass (kg)	82.2 ± 15.0	77.9 ± 18.2
Quadriceps skinfold (mm)	11.6 ± 6.0	7.7 ± 4.6
BMI (kg/m^2)	26.2 ± 3.8	26.2 ± 4.6
1RM leg press (kg)	317 ± 107	307 ± 96

NM: naturally menstruating (cycle length between 21-35 days and at least 9 consecutive periods in a year).

Table 2. Distribution of excluded samples for CON and COMP groups for each target protein (pooled timepoints).

Target protein	**Excluded samples (n)**		**Total samples retained for analysis (n)**
	CON	***COMP***	
mTOR	5	6	69
P70S6K	0	0	80
rps6	0	0	80
4E-BP1	0	0	80
eF2	0	2	78
p-mTOR	9	11	61
p-P70S6K	16	16	48
p-rps6	8	8	64
p-4E-BP1	8	8	64
p-eF2	1	2	77

4E-BP1, eukaryotic initiation factor 4E binding protein; eF2, eukaryotic elongation factor-2; mTOR, mammalian target of rapamycin; p = phosphorylated protein content; p70S6K, p70 kDa ribosomal protein subunit kinase 1; rps6, ribosomal protein S6.

Table 3. Summary of muscle blood flow, blood measures (lactate and glucose) and perceptual measures (MS, TQR and SWS) for CON and COMP groups, presented as mean ± SD for each timepoint.

			Timepoint			
Measure	***Condition***	***Baseline***	***Post-exercise***	***1-h post***	***5-h post***	***24-h post***
Muscle blood flow (mL/min·100/g)	CON	0.13 ± 0.05		0.15 ± 0.04#	0.13 ± 0.03	0.13 ± 0.04
	COMP	0.13 ± 0.04		0.16 ± 0.05#	0.13 ± 0.05	0.14 ± 0.03
Lactate (mmol/L)	CON	0.56 ± 0.43		0.69 ± 0.33#	0.51 ± 0.27	0.38 ± 0.12
	COMP	0.45 ± 0.19		0.68 ± 0.15#	0.47 ± 0.18	0.44 ± 0.11
Glucose (mmol/L)	CON	4.50 ± 1.23		3.88 ± 0.83#	4.90 ± 1.33	4.53 ± 1.05
	COMP	4.92 ± 0.72		4.32 ± 0.51#	5.07 ± 0.82	4.98 ± 0.54
MS (AU)	CON	0.9 ± 1.3	3.5 ± 2.2#	2.4 ± 2.0#	2.2 ± 1.4#	3.8 ± 2.4#
	COMP	1.5 ± 1.1	3.5 ± 2.2#	3.3 ± 1.7#	3.2 ± 1.3#	4.8 ± 1.9#
TQR (AU)	CON	16.4 ± 2.7	13.6 ± 2.2#	15.2 ± 2.4#	15.5 ± 2.5#	14.4 ± 2.0#
	COMP	17.2 ± 1.6	12.0 ± 2.9#	13.9 ± 1.7#	14.2 ± 1.6#	14.6 ± 1.4#
SWS Total Score (AU)	CON	19.6 ± 2.5				17.1 ± 2.0#
	COMP	17.4 ± 1.4				16.8 ± 1.2#

MS = muscle soreness; SWS = subjective wellbeing survey; TQR = Total Quality of Recovery. # indicates significant ($p < 0.05$) difference from baseline for both groups.

Table 4. Summary of performance measures (CMJ and IMTP) for CON and COMP groups, presented as mean ± SD for each timepoint (baseline, post-exercise, 5-h post and 24-h post).

		Timepoint			
Measure	***Group***	***Baseline***	***Post-exercise***	***5-h post***	***24-h post***
CMJ height (m)	CON	0.33 ± 0.07	0.30 ± 0.06#	0.32 ± 0.06#	0.33 ± 0.08#
	COMP	0.35 ± 0.09	0.32 ± 0.09#	0.31 ± 0.06#	0.31 ± 0.06#
CMJ RSI-mod (m/s)	CON	0.40 ± 0.11	0.39 ± 0.09	0.42 ± 0.12	0.41 ± 0.14
	COMP	0.46 ± 0.10	0.43 ± 0.11	0.41 ± 0.06	0.40 ± 0.06
CMJ push off force impulse (N·s)	CON	202 ± 46.4	201 ± 38.3	200 ± 42.8	201 ± 46.2
	COMP	197 ± 48.3	197 ± 44.4	189 ± 47.4	186 ± 41.6
CMJ push off time (s)	CON	0.27 ± 0.04	0.27 ± 0.05	0.27 ± 0.05	0.28 ± 0.04
	COMP	0.26 ± 0.02	0.28 ± 0.04	0.26 ± 0.02	0.26 ± 0.02
IMTP net force at 100ms (N)	CON	237 ± 149	217 ± 136	305 ± 177	317 ± 145
	COMP	297 ± 152	338 ± 162	317 ± 139	327 ± 189
IMTP net force at 200ms (N)	CON	694 ± 387	609 ± 338	763 ± 378	840 ± 376
	COMP	768 ± 347	842 ± 326	824 ± 291	791 ± 324
IMTP net peak vertical force (N)	CON	1963 ± 792	1794 ± 720	1830 ± 621	1978 ± 636
	COMP	1779 ± 415	1646 ± 299	1647 ± 255	1662 ± 338

CMJ = countermovement jump; IMTP = isometric mid-thigh pull; RSI = reactive strength index. # indicates significant ($p < 0.05$) difference from baseline for both groups.