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THE EFFECTS OF CONTRAST WITH COMPRESSION THERAPY ON MUSCLE RECOVERY POST EXERCISE

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THE EFFECTS OF CONTRAST WITH COMPRESSION
THERAPY ON MUSCLE RECOVERY POST EXERCISE

BY

RYAN OAKLEY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

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OF

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2019

ABSTRACT

This study investigated the effect of combining contrast with compression therapy as a post exercise recovery modality. Previous research indicates that contrast and compression alone can potentially enhance recovery but the combination of the two is yet to be explored. Ten recreationally trained males between 18 and 35 were recruited (years 21.25 ± 2.12 ; height 182.1 ± 8.5 cm; weight 88.04 ± 19.49 kg) in a randomized control trial with a repeated measure (within subject) crossover design. The conditions were randomly assigned by dominant/non-dominant arm and contrast with compression (CwC) or control (CON) in which one arm was used for each condition. Participants completed 30 eccentric elbow flexor repetitions and were subsequently tested at six timepoints (pre, immediate post, 1 h, 24 h, 48 h, and 72 h) for power, strength, swelling, range of motion (ROM), and perceived soreness. The CwC condition received treatment after post testing, at 24 h and 48 h; the CON condition did not receive any treatment. CwC resulted significantly improved recovery in power, strength, and swelling ($p \leq 0.05$). However, no difference was seen in ROM and perceived soreness. Conclusion: CwC can be used as a post exercise recovery technique to improve muscular performance and reduce swelling in recreationally trained individuals.

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CHAPTER 1

INTRODUCTION

Recovery from exercise is an important factor for professional and recreational athletes. Full recovery between bouts of exercise, practice or competition allows athletes to be able to perform at a higher level in subsequent bouts. However, athletes training and competition schedules often do not allow them to fully recover between bouts of exercise resulting in decreased levels of performance and increasing the risk of injury¹⁻⁴. Along with a drop off in performance, incomplete recovery can lead to overtraining, which is caused by an imbalance of energy expenditure load and recovery⁵. Consequently, athletes often take part in various recovery therapies / techniques in the hopes of accelerating recovery^{6,7}. Two common forms of recovery therapies are contrast therapy (alternated exposure to hot and cold) and compression therapy.

Intense exercise through game-play, weight training, or unaccustomed exercise can cause a disruption in the muscle tissue called exercise induced muscle damage (EIMD) which can lead to hindered functional activity, delayed on set muscle soreness (DOMS), loss in range of motion (ROM), and inflammation / swelling⁸⁻¹⁰. EIMD is primarily caused by eccentric muscle contractions, i.e. when a muscle is forcibly lengthened. This type of contraction can be stimulated through resistance training but often occurs in sports during tasks such as landing, decelerating and changing

direction. These eccentric muscle contractions can subsequently cause a disruption in the sarcomeres which damages the excitation and contraction coupling system and leads to a less efficient muscle contraction^{10,11}. Eccentric exercise has been shown to result in muscle soreness, swelling, and loss of range of motion, power and strength loss; these signs typically start at 24 h and peak between 24-72 h but can be seen for up to 11 days¹². One study reported a differences in recovery of eccentric exercises between upper body and lower body exercises, claiming that upper body exercises give more pronounced symptoms of DOMS compared to the lower body¹³.

Compression garment therapy has been widely studied and been shown to improve the rate the recovery^{3,14}. This therapy can take form of a single sleeve¹⁵, a garment for the legs³, or a whole body suit¹⁴ which can be used before, during, or after an activity¹⁶. Compression of a muscle has been linked to increase venous pump which allows blood to be returned to the heart at a faster rate and waste products to then be removed¹⁴. Blood flows at higher velocity due to the decreased diameter of the vessels as explained by the Bernoulli's principle. The use of these garments can also aid in recovery of muscle function such as strength and power while reducing swelling, and perceptual pain¹⁶. Compression garments can vary in pressure depending on the brand and size and are usually worn for extended periods of time, which often make them impractical. However, smaller bouts of compression therapy are being used as a more efficient post exercise recovery. Pneumatic compression sleeves can offer more compression along with sequential compression that starts at the distal end of an extremity and pulses up to the core, which helps aids in further blood return and waste

products/metabolites to the core. The effectiveness of using this device in the biceps brachii when receiving the treatment for multiple days has been shown to decrease swelling, DOMS and increase range of motion after heavy eccentric exercise¹⁷.

Cold-water-immersion (CWI) and hot-water-immersion have been used as single modalities to accelerate recovery after intense exercise¹⁸. CWI has been shown to decrease muscle temperature, which decreases blood flow by constricting the vessel, therefore it reduces edema by slowing down inflammation mediators (e.g leukocytes), which leads to less swelling. Furthermore, it acts as a local anesthetic by decreasing the activation threshold of the tissues nociceptors and the conduction speed of pain nerve signals¹⁹. A meta-analysis has shown that pain measures after using CWI below 15° C after exercise can lower the perception of DOMS from 24-96 h compared to a control²⁰. On the other hand, heat vasodilates the vessels, increasing the blood flow which removes metabolites, damaged tissues and free radicals^{6,21}.

The combination of both hot and cold-water therapies is known as contrast water therapy (CWT). CWT is a common tool that is used to recover from an intense workout bout and it has been shown to decrease the time to baseline in athletic performance^{1,22-24}. CWT works by hyper reactive vasodilation during the heating phase and vasoconstriction during the cold phase, which in turn helps increase circulation, removing metabolites and free radicals, decreasing inflammatory response, and slowing the metabolic process down^{18,22,25}. The use of CWT alone has been proven to be superior to passive recovery but has reported little difference compared to

compression, stretching, cold water immersion and active recovery⁷. Furthermore, the effects of contrast water therapy at various ratios and temperatures have been looked at with varying degrees of significance with the most common being 1:1, at cold (15° C) to hot (38° C) from 10-14 min^{7,18,22,26}. It has also been reported that there doesn't seem to be a dose response when comparing CWT at 6, 12 and 18 min²³.

Compression therapy and CWT aren't alone in their attempt to shorten recovery time as massage therapy²⁷, CWI²⁰, stretching²⁸, and active recovery²⁹ all being used in athletic fields. A meta-analysis performed in 2018 suggested that massage therapy was most effective at reducing DOMS and perceived fatigue with CWI and compression garments also positively effects these variables, but gave no inclination to athletic performance⁶. The potential of combining modalities for greater recovery effect has started to receive some attention. For example, a study looked at combining compression therapy with cryotherapy (cryocompression)⁴ and yielded closer to baseline scores in 24 and 48 h in power and soreness measures. Pairing cryotherapy with compression may increase the effects of both therapies as compression therapy may mitigate the vasoconstriction that is associated with cryotherapy while maintaining beneficial neurological and metabolic changes.

To our knowledge no research has been performed to determine the potential benefits of combined contrast and compression therapy (CwC) as a post exercise therapeutic intervention. Therefore, we explored the use of CwC when used once a day for three day in 10 min bouts. With the lack of definitive knowledge of a superior modality for

recovery, the need to enhance what has already been studied should be explored. With greater recovery from exercise it will allow for better day to day training, workouts or game performances and could improve the efficiency of a program and sport performance³⁰. Thus, the purpose of this study was to determine the effects of contrast with compression on performance and recovery parameters following a heavy eccentric exercise bout. We hypothesized that CwC will lead to shorter recovery times in both muscular performance and other recovery parameters measured.

CHAPTER 2

REVIEW OF LITERATURE

Contrast Water Therapy (CWT) on recovery:

A meta-analysis was conducted by Bieuzen *et al.*⁷ on contrast water therapy (CWT) which consisted of 18 studies. All studies looked at the use of contrast therapy (<15° C and >35°C) within 1 h post exercise; measurements were taken <6, 24, 48, 72 or 96 h post exercise. Measures used to analyze muscle damage where; muscle soreness (as measured by a visual analogue scale: VAS), muscle damage [creatine kinase (CK)], lactate dehydrogenase (LDH), myoglobin, inflammatory biomarkers (IL-6), muscle strength, and muscle power (vertical jump). When comparing the results to a passive control the results showed less of a loss in muscle strength, muscle power, and perceived pain from baseline for all time points. However, there was no difference in IL-6, and CK only showed a difference at 48 and 72 h. This study concluded that CWT is superior to passive recovery but showed little difference between other measures of recovery [compression, active, cold water immersion (CWI) and stretching] and therefore no superior method was seen in these 18 studies, but all proved better than a passive control.

Dupuy *et al.*⁶ also conducted a meta-analysis to compared recovery techniques to see which has the best results from current literature. No muscular performance measures

were, instead DOMS, perceived fatigue, inflammatory marker [C-reactive proteins (CRP) and Interleukin-6 (IL-6)] and muscle damage markers (CK) were analyzed. This meta-analysis included 80 articles for DOMS, 17 for perceived fatigue and 43 for muscle damage and inflammation. Techniques compared were: stretching, massage, massage combined with stretching, compression garments, electrostimulation, CWI, CWT, and hyperbaric therapy/stimulation. While not all modalities proved to help with recovery CWT, compression, massage, CWI, active recovery, and cryotherapy had a positive impact on DOMS. Only massage therapy also had an impact on perceived soreness and had the saw improved recovery on CK concentration and IL-6. CWT also reduced CK concentrations in the blood indicating reduced muscle damage.

Vaile *et al.*²² conducted a study on recreationally trained athletes in which they acted as their own controls in a cross over design with a six-week wash-out period. This study compared CWT to a passive control after a heavy eccentric workout bout and tracked various variables related to muscle damage. Five sets of 10 eccentric bilateral leg presses at 140% 1RM to induce muscle damage, after which they entered one of the two recovery techniques: a passive recovery for 15 min, or CWT for 15 min using a cold-hot ratio of 1:2 (8-10° C to 40-42° C). Measures were taken immediately after treatment along with, 24, 48 and 72 h post recovery and the measurements taken were isometric front-squat strength, lower body power during a jump squat while lifting using 30% of their maximal load, CK, thigh volume using a tape measure, and VAS for perceived soreness. Results showed that CWT resulted in smaller loss of isometric strength ($p < 0.05$), power ($p < 0.006$), and smaller increase in thigh volume ($p <$

0.01); however, there was no significance reported in perceived pain. The author speculated both hot and cold increases the sympathetic drive of the nervous system and the pumping effect could circulate blood around the body with the use of vasoconstriction and vasodilation, which will also help with further metabolite clearance.

Vaile *et al.*¹⁸ conducted another study looking at three different hydrotherapy techniques and a control group. Participants were randomly assigned to one of the four groups: 1) CWI (15° C, n = 12), 2) hot water immersion (38° C, n = 11), 3) CWT with a ratio of 1:1 (CWT, 15° C: 38° C, n = 15), 4) passive control (CON) all hydrotherapy modalities required full body submersion and for 14 minutes total. Muscle damage was induced by 5 sets of 10 repetitions of eccentric bilateral leg presses at 120% of their 1RM. Measures included isometric squat (force plat form), peak power (jump squat), blood markers (CK, LDH), thigh circumference (tape measure), and perceived soreness (VAS). All three water therapies faster recovery in isometric force compared to CON but only CWI and CWT improved recovery in dynamic power and decreased swelling ($p < 0.05$).

Versey *et al.*²³ compared the duration of CWT on recovery on running performance. There were four recovery techniques: a control, and three CWT groups at 6, 12 and 18 min (15-38° C). Participants were long distance runners used to covering > 60 km/week and were not used to hydrotherapy. It was a crossover design counterbalanced at least 4 days apart. Two hours was given between the first workout

and the second and running performance (3000m), pain to pressure threshold, perceived exertion, heart rate and leg girth were also taken during this study for measurements. This study reported that 6 min of CWT induced a faster running time on the second trial than control (87% probability, $0.8 \pm 0.8\%$ mean $\pm$ 90% CL); however, 12 min (34%, $0.0 \pm 1.0\%$) and 18 min (34%, $-0.1 \pm 0.8\%$) had no effect. This implies that CWT does not have a dose response to running performance in a cold environment but implies 6 min of CWT is significantly better than 12 min, 18 min and a control. However, with the small sample size for each group it is hard to draw any real conclusion. Therefore, Versey *et al.*¹ employed a similar study design but on 5 min cycling performance and peak power and did not see a dose response when comparing 6, 12, and 18 min of CWT to a control. This time, the 5 min timed bike trial did not differ between conditions. The total work performed in the 5-min time-trials after 6 min of CWT was greater than control (75% probability; $1.5 \pm 2.1\%$, mean $\pm$ 90% CL) and CWT18 (99%, $2.5 \pm 1.2\%$), but not 12 min of CWT. Exercise bout of one 15-s sprint total work was greater in 6 min CWT (75%, $2.0 \pm 2.7\%$) and 12 min of CWT (94%, $3.0 \pm 2.2\%$) than control. The total work performed in the 15 s sprints after 6 mins of CWT and 12 mins of CWT was greater than control (6 min: 87%; $3.0 \pm 3.1\%$, 12 min: 95%; $4.3 \pm 3.4\%$), with 12 min of CWT also being greater than 18 min (78%, $1.9 \pm 2.2\%$). The average peak power after 12 min of CWT was greater than for the three other trials (control: 77%; $2.7 \pm 3.8\%$, 6 min: 82%; $2.5 \pm 2.6\%$, 18 min: 76%; $2.7 \pm 4.0\%$). In conclusion 12 min of CWT seemed to have more benefits than 6 and 18 minutes but it was not definitive across all measure. Again, this

suggests that CWT does seem beneficial but there is no dose response seen after 12 min.

Studies looking at sports teams and using either simulated or actual practice/ game-play to stimulate enough muscle damage yields varying results in the field. The following studies show that CWT can offer benefits at certain time points and other failed to find significance. Bleakley *et al.*²⁰ conducted a systematic review on sports teams and the use of CWT and CWI. This analysis consisted of a total of 606 participants in and assessed recovery in 8 different sports. Only CWI showed significance in countermovement jump at 24 hours ($p = 0.05$, CI: 20.00 to 0.58). However, both CWT and CWI showed significance in perceived fatigue. Both modalities failed to effect perceived soreness following team sport. Five trials compared CWI to CWT and reported no significant differences in all variables. Interestingly in the study, by 48 h, irrespective of recovery intervention, control and hydrotherapy intervention all groups had returned to within 2% of baseline scores for countermovement jump, which may indicate that the game/training play did not induce severe muscle damage.

Higgin *et al.*²⁵ performed a systematic review and meta-analysis on well trained sports teams (1997-2014) and 23 articles were reviewed. CWT affected perceived fatigue and recovery directly after but not at 24 and 72 h after exercise. CWI helped improve countermovement jump and sprint time but only at 24 h time point suggesting that CWI may offer neuromuscular recovery during this time frame. CWT didn't show

statistical evidence of improved recovery in countermovement jump and perceived soreness. Only one study had data on sprint time and therefore a meta-analysis was unable to be complete on CWT.

Crowther *et al.*²⁶ compared the effect of different recovery strategies upon performance and perceptions following a fatiguing exercise in a randomized control trial consisting of 34 recreational athletes. This study compared 5 recovery techniques: CWI, CWT, active recovery, a combined cold-water immersion and active recovery (COMB) and a control condition which were all 14 min each. Participants were tested on sprint ability, countermovement jump, sit and reach, and perceived recovery. In conclusion of all protocols, CWT was rated as the most effective recovery strategy by most participants (50%), followed by COMB and CWI (29% each). Additionally, only CWT showed superior benefits at 1h in perceived soreness while only the active recovery showed better peak power recovery at 1 h. There was no change in flexibility throughout all timepoints and no difference in groups for all variables at 24 and 48 h. These finding suggests that psychologically non-athletes feel more recovered using CWT, but it may not offer many benefits after a 1h time point.

Robey *et al.*³¹ compared CWT to static stretching and a control and saw no differences amongst the three groups. Recovery procedures were administered at three time points (immediate post, 24 h and 48 h). They used a strenuous stair-climbing run (up and down) as the protocol to induce muscle damage, but muscle damage (CK), perceived

soreness, peak torque and rowing ergometer (2 km times) showed no significant differences between groups. This may have been because the muscle damaging protocol did not stimulate much damage.

French *et al.*⁸ looked at compression garments (CG) and CWT compared to CON in recreationally trained athletes with >1 year of resistance training and >4 years training in their given sport (soccer and rugby). The CB group switch from a cold bath (8-10° C) and a hot bath (37-40° C) at a ratio of 3:1 starting and ending with cold. The compression group wore commercially available compression shorts for 12 hours post exercise. The muscle damaging exercise used was six reps and ten sets of parallel back squats with a load relative to 100% body mass. At the end of every set a single 5 s eccentric back squat against a load relative to the participant's predicted 1 repetition max was implemented and then followed by 2 min of rest. Interestingly this study suggests that none of these recovery methods prove superior when evaluating power, strength, speed, ROM, circumference, perceived soreness, agility and CK.

Compression Therapy on recovery

A systematic review with meta-analysis by Marques-Jimenez *et al.*¹⁶ looked at whether compression garments are an effective tool to aid in recovery after muscle damage has been induced. Twenty studies met the inclusion criterion which were: randomization in to control (CON) and compression group (CG), the measuring of at least one variable from baseline to 10 min after, the application of CG either before,

during, or following exercise, or a combination of the three. The studied consisted of moderated low pressures (average pressure of 10–20 mm Hg). In conclusion, muscle swelling perceptual measurements, power, and strength indicate faster recovery of muscle function after exercise amongst a heterogenic population.

Another meta-analysis this time from Hill *et al.*² a few years prior to Marques-Jimenez's review also concluded the same kind of results. From 12 studies variables were measured up to 72 h post exercise and showed that compression therapy can assist in recovery after muscle damage has occurred. Measurements of muscular power included any activity that measured the explosive power of the muscle; examples include a counter-movement jump and a 5 m sprint. Muscular strength included measurements of isometric/isokinetic/isotonic muscle contractions. Measurements of DOMS were obtained using VAS or Likert scale. DOMS (95% CI 0.236 to 0.569, $p < 0.001$), muscle strength (95% CI 0.221 to 0.703, $p < 0.001$), muscle power (95% CI 0.267 to 0.707, $p < 0.001$), and CK (95% CI 0.171 to 0.706, $p < 0.001$).

The use of compression garments for athletic recovery has been studied extensively, however these are often worn for long periods of time, which can make them impractical. Pneumatic compression (PC) devices have received relatively little attention in the literature compared to cryotherapy, as it is relatively new to in the field exercise recovery. Originally such garment was used for in the post-surgery phase and to treat thromboembolism, deep vein thrombosis and prevent venous stasis³². PC

garments can inflate in separate compartments, starting at the most distal end and making its way to the center of the body, therefore increasing blood return, waste products/metabolites to the core. Winke *et al.*¹⁷ investigated using the pneumatic device for 20 min immediately post, 24, 48, 72, 96, and 108 h post exercise compared to wearing a CG continuously for 5 days post eccentric exercise. Swelling, ROM, and pain returned to baseline faster in the PC group ($p < 0.05$). More specifically, arm circumference reached significance when tested at 12 cm above the elbow crease but not 3 cm above. Both elbow extension (passive) and elbow flexion (active) reached significance and favored the PC group which affected the ROM results. Perceived soreness using a VAS was significantly different in the PC group during active and passive flexion compared to the compression sleeve. However, palpation VAS didn't reach significance. This study did not look at the possible performance outcomes of strength or power to relate it directly to faster recovery in sports performance. Also, the pressure of both devices was not measured, however, the PC was expected to be more intense than the compression sleeve.

Conversely, Cochrane *et al.*³² reported that 30 min of PC was unable to hasten muscle recovery in the legs of healthy young males when only looking at strength measures. Single leg isometric, concentric, and eccentric measures were taken 24, 48 and 72 h after the muscle damaging exercise with 14 days used between legs in a cross over design. Diller *et al.*³³ also reported that both occlusion of blood to the lower extremity and PC did not differ from a control group. A cross-over design was used with isokinetic strength, vertical jump, and perceptual measures of recovery taken at 1 and

24 h after the muscle damaging exercise of 10 sets of 10 repetitions of back squats at 70% of maximum load.

For short term recovery Martin *et al.*³⁴ used a randomized cross over design to look at the effect of PC on blood lactate clearance in repeated in Wingate tests. After 2 Wingate tests separated by 3 min, the subject with received PC (30 min) or a sham and had a blood sample taken at 5, 15, 25, 35 min. Once the recovery was complete, another Wingate was administered. Blood lactate was shown to be reduced after 25 min in the PC group however, anaerobic power markers returned to baseline for both groups making it hard to relate it to short term recovery for anaerobic power.

Kraemer *et al.*¹⁵ used a between group design to compare a CG in the form of an arm sleeve to a CON after an eccentric exercise. The CG was worn continuously for 108 h and at 72 h the CG experienced less of a decrease in strength and power compared to the CON group. Furthermore, significantly less swelling (circumference) and change in passive elbow flexion was seen in the CG.

Combing cold and compression therapy (i.e. cryocompression) is a colloquial method used in the field but DuPont *et al.*⁴ was the first to study this by looking at its effects on recovery compared to a CON group from 16 resistance trained men. Testing took place, before, immediately after and 1, 24 and 48 h after the heavy resistance training exercise. The exercises consisting of back squats at 80% of their one repetition max for 4 sets of 6 repetitions with 90 s rest between sets, 4 sets of 8 repetitions of stiff

legged deadlifts using weight equivalent to their body mass with 60 s rest between sets, and 10 Nordic hamstring curls with 45 s rest between reps. Cryocompression was used for 20 min immediate post, 24, 48 h post exercise. The cryocompression submerged both legs and was approximately (8-10° C) with a pressure of 12 PSI. Significance ($p \leq 0.05$) was reported at 24 and 48 h for the power (W), CK, rating of soreness (VAS), and sleep.

Kraemer *et al.*¹⁴ also compared whole body compression as each participant acted as their own control in a randomized in group treatment design on marker of recovery after 24 h. Eleven men and nine women that were resistance trained for a minimum of 2 years performed eight exercises that targeted all major muscles in the body for 3 sets of 8-10 repetitions. A wash out of at least 72 h was used in between each group. Subjective measures (3 perceived visual analogue scales, a 10-point general fatigue scale, one Profile of Mood States scale, a 6-point vitality scale, and one sleep scale/log), blood (CK & lactate), swelling, reaction time, and power were all tested and showed that the whole-body compression group had improved recovery in all variables other than power. As the compression was not localized and only consisted of mild compression this could be the reason for no change between conditions.

Jakeman *et al.*³ isolated the lower limb with a compression garments to investigate recovery in young active females in which muscle damage was induced by 10 sets of 10 repetitions of plyometric drop jumps. They employed a randomized control trial

with eight participants wearing CG and nine in the CON group. The CG group wore compression tights for 12 h after the muscle damaging activity. Muscle soreness peaked 24-48 h but was lower in compression group. Vertical jump and isokinetic muscle strength saw less of a drop off with the compression group. Compression was thought to reduce edema, which also lowered the perceived pain felt by the experiment group due to less pressure on the nerve endings. Also, it is thought that compression acts like a “dynamic cast” that helps with muscular repair by holding the muscle in place to allow the sarcomeres to re-align after exercise.

Hill *et al.*³⁵ compared a lower leg CG to a CON group on 24 marathon runners post-race. The CON group wore the garment for 72 h while the control group did a fake ultrasound test to act as a placebo. The CG group only showed significance in lower perceived soreness at 24 h ($p \leq 0.05$) compared to the CON group but no differences were seen in max voluntary isometric contractions (MVIC).

CWT and compression conclusion: Alone, there is mixed evidence supporting CWT, but several meta-analyses showed that it increases recovery parameters.

However, there are a lot of studies that do not provide enough EIMD to draw conclusion especially when performed in an athletic population using game-play stimuli. Research on low intensity and long duration compression has been conducted yielding favorable results for recovery. However, when compared to PC it was shown to be inferior when comparing swelling, DOMS and range of motion but there is little evidence to show that when used alone it can improve performance. Furthermore,

when PC in combined with cold therapy one study showed that it can improve power output.

Exercise induced Muscle damage

The DOMS model is explained by McArdle *et al.*⁹ as to be caused by unaccustomed exercise using eccentric muscle actions; for example running downhill (working the quadriceps) or lowering weights slowly during resistance training. Eccentric exercises are usually followed by reduced muscle force and the release of cytosolic enzymes (creatine kinase) and myoglobin. Damage is also seen in the contractile myofibrils and non-contractile structures (tendons). The increase of metabolites in the muscle causes even more damage and lack of force. Starting around 24 h the feeling of DOMS will appear and is the result of inflammation, tenderness and pain. Lastly, as the inflammation process begins the muscles start to heal and adapt, therefore making them more resistant to damage from subsequent exercise.

Proske *et al.*¹⁰ summarized eccentric exercise such as mechanisms, adaptations and clinical applications. Eccentric exercise causes muscle damage observed through microscopic examinations that show sarcomeres out of lines with one another, Z-line streaming, over-extended sarcomeres, regional disorganization of the myofilaments and t-tubule damage. When someone is unaccustomed to this kind of exercise they will start to feel DOMS (i.e. soreness starting at 24 h after exercise which peaks 2-3 days after exercise). However, if one was to perform the same exercise a week or two later they will not be as sore due to adaptations of the muscle to stop further damage

and this is known as the repeated bout effect. It has been theorized that there are two reasons behind muscle damage; one is a disruption in the sarcomeres and the other is damage to the excitation and contraction coupling system. Excitation and contraction coupling system is the link between the excitation of a neuron to stimulate an action potential in the muscle fiber sarcolemma which causes a muscle to contract through the release of calcium.

Clarkson¹¹ reports that eccentric actions performed at long muscle length cause more damage than when shortened. When the muscle is extended and under force it is thought that the weakest sarcomeres become passive and put more strain on the others. The reason for the inability to extend the arm may be explained by swelling, a change in properties of supporting connective tissue, and/or non-neurally mediated contractures.

Twenty-six female students performed 70 eccentric contractions on the elbow flexors and compared the results to their other arm. Swelling peaks significantly ($P < 0.01$) at 24 h up to 96 h, the resting angle of the elbow joint decreased significantly after and peaked at day 4, a loss in strength was seen after exercise and peaked at 24 h but still showed significant decreases after 11 day (-20%), tenderness at the mid-belly peaked at 48 h post and returned to baseline after 7 days, and pain/soreness was seen at 24 h, peaked at 72 h and no longer existed at day 8. Therefore, eccentric exercises were effective in producing tenderness, swelling, muscle shortening, and strength loss. The study showed that pain is not necessarily related to strength as no pain was felt

immediately after the exercise but there was a big reduction in isometric strength post exercise and at 24 h¹².

Jamurtas *et al.*¹³ compared the differences in recovery between eccentric strength of the legs and arms. There were eleven untrained males in a crossover design with a minimum of 14 days rest between muscle groups. They performed 6 sets of 12 repetitions at 75% of max eccentric torque for leg extensor and elbow flexor using an isokinetic dynamometer. ROM, DOMS, CK, LDH, myoglobin, muscle strength and eccentric peak torque were measured. In summary, arms had a significantly larger difference compared to legs at 72 and 96 h compared to legs for CK and Mb levels, which is a sign of continued increased muscle damage.

Nosaka *et al.*³⁶ studied repeated bout effect. They concluded that the more eccentric contraction done on the first exercise session the greater change in all dependent variables (maximal isometric strength, range of motion, upper arm circumference, muscle soreness, plasma creatine kinase activity and myoglobin concentration) and that the reduced load of doing only 2 or 6 eccentric contractions compared to 24 produced the same defense mechanism of the repeated bout effect when all groups performed 24 eccentric contractions 2 week later. This could affect the amount of muscle damage seen a participant when their regular weekly physical activity varies.

Variables chosen:

Huw *et al.*³⁷ investigated the load required to achieve peak power in upper and lower body strength in rugby players. Upper body strength was measured by a ballistic bench throw (BBT) and lower body strength via a squat jump (SJ); both exercises were performed at 20, 30, 40, 50 and 60% of their 1RM. Peak power for the upper body was with an external load of 30% ($p < 0.001$) and lower body at 0%. Power loss after muscle damage has also been shown in many recovery studies and vary in efficacy to return power to its pre EIMD state within 72 h^{1,2,31,3,4,7,14,16,22,25,26}. Power is an essential factor for athletic performance, therefore, the lack of power after EIMD can affect an athlete's ability to perform at their peak³⁸.

Strength decreases after muscle damage can be as much as a 60% from baseline and is prevalent even before soreness is perceived¹¹. Due to disruption in the sarcomere placement, and sensitivity to contract through the excitation and contraction coupling theory, strength is often used to measure muscular recovery^{4,14,16,39}.

Lau *et al.*⁴⁰ looked at measuring DOMS through VAS scales. As DOMS is often felt the day after a strenuous workout, usually consisting of eccentric work and can peak up to three days after a workout; it is characterized by a dull, aching pain usually felt during movement or palpation. Different pain scales are used to rate DOMS such as: VAS, verbal rating scale, numerical rating scale, and descriptor differential scale. VAS and pain to pressure threshold (PPT) are used to measure DOMS^{41,42}, however they do not correlate as VAS has been shown to peak at day two and PPT at day one post exercise. The two methods differ as a VAS lets us know the severity of the pain felt

after a set stimulus but PPT shows us the level of palpation a participant starts to feel pain.

Swelling is often used when looking at muscular recover due to the inflammation that occurs at a given sight. Swelling is mostly measured as circumference^{1,8,12,15,18,22} due to the feasibility of a tape measure, but intramuscular swelling can also be seen using ultrasound^{7,14}. Due to the necrosis of some muscle fibers during repeated eccentric contractions there is an inflammatory response consisting of leukocytes and neutrophils that cause edema⁹.

Many studies use ROM^{8,12,26} when looking at muscular recovery from an exercise and when they are specifically looking at the bicep this can be achieved by measuring the passive flexion and active flexion of the arm as shown by Kuligowski *et al.*²⁴. It was once thought that muscle pain was the reason for decreased angle of a joint but there has been no correlation^{10,12}.

Lactate acid is the result of energy produced by the anaerobic glycolytic pathway. As hydrogen ions build up, we start to fatigue due to metabolic acidosis (increased pH) in short term high intensity exercise. Lactate is correlated with glycolysis therefore exercise that requires high amounts of glycolysis will cause more lactate to be produced²⁹.

CHAPTER 3

METHODOLOGY

Design: A randomized control trial with a repeated measure (within subject) crossover design was conducted. In this study, each of the 10 participants completed two subsequent single-arm elbow flexor workouts after which they received either CwC therapy or no treatment (see Figure 1). After each workout follow-up measurements of muscle performance, perceived soreness, ROM, and inflammation were taken at six time points (before, immediately after and 1, 24, 48, and 72 h after exercise).

Participants were recruited from The University of Rhode Island by flyers and word of mouth. To qualify to take part, participants had to be 18-35 years old, male, not on any anti-inflammatory drugs, and have had no upper extremity injury in the last 6 months. Additionally, throughout the study participants were required to come to testing euhydrated, and refrain from exercise and alcohol throughout the study. Once participants attended a single information meeting and signed an informed consent they were then scheduled to participate in the study and were randomly assigned to a condition based off control/intervention and dominant/non-dominant arm in the first week; the second week would subsequently be the opposite (see Figure 1). All testing was completed in the Human Performance Lab at The University of Rhode Island. IRB approval was received on September 21, 2018 and data collection took place between September 24, 2018 to February 14, 2019.

Figure 1. Randomization flowchart

Figure 2. Testing timeline

Procedure and intervention

Prior to any testing the participants weight, body fat percentage, and the lean mass of both arms were calculated using the Bioelectrical Impedance (BIA) (InBody 770 scanner, Seoul, Korea), and height was taken using the stadiometer. Baseline, immediate post and 1 h post exercise testing was administered around the exercise intervention on the first day of the study and again once they switched arm and condition (day 5). Follow-up testing was complete at 24, 48 and 72 h after they

performed each condition. To account for circadian rhythm, participants performed all testing at the same time.

Controls

Contrast with compression and control: When assigned to the intervention condition participants received CwC three times; after the immediate post-exercise testing, before the 24 h post-exercise testing, and before the 48 h post exercise testing (See Figure 2). CwC was administered to the exercised arm via a 12” pressurized cuff, which alternated between flowing hot (42° C) and cold (8° C) fluid. The cuff was strapped around the upper arm firmly and held in place by two Velcro straps which are a part of the cuffs design. During the treatment, a temperature-controlled fluid would flow through the bladder network adding compressive forces. The contrast therapy consisted of 10 min of treatment where fluid temperature would alternate between hot and cold in 1 min intervals so that each participant received five total hot-cold cycles each therapy session. The control (CON) condition did not have any type of recovery intervention but still repeated the same testing procedure.

Figure 3. CwC machine, cuff, and tablet

Descriptors

Anthropometrics: Prior to the testing sessions we gathered the participants anthropometric information. The BIA (InBody 770 scanner, Seoul, Korea) was used to measure weight, body fat percentage, and lean mass of both arms (see Figure 4). To ensure accuracy, participants came in hydrated and were weighed in minimal garments. A stadiometer (Seca 213, Chino, CA) was used to measure height without shoes.

Figures 4. InBody bioelectrical impedance

Hydration: Measures of swelling, strength and power could be affected by the hydration levels of each participant; therefore, it was measure at the beginning of every testing day. Urine specific gravity (USG) was measured using a handheld refractometer (ATAGO USA, Inc.) to ensure that participants were euhydrated which was defined in this study as a $USG \leq 1.025$. If USG was > 1.025 participants sipped water and were periodically retested until $USG \leq 1.025$ prior to taking part in any testing.

Lactate: Lactate measures were taken to ensure equal amount of muscle damage was seen in both conditions. Lactate measurements were taken pre, post, and 1 h after the exercise intervention. After a finger stick the blood was collected through a lactate analyzer (Nova Biomedical, Waltham, MA) and a result was given in mmol.

Intervention

Muscle Damaging Protocol: The participant was set up according to the elbow extension/flexion (seated) protocol explained in the Biodex manual (see Figure 6) ⁴³. The dynamometer orientation was set at 30°, tilt and chair orientation 0°, with the axis of rotation passing through the center of the trochlea and capitulum, elbow support at 45° elbow flexion and strapped with the Velcro, handle of the lever positioned in the participants palm, with the rest of the body strapped to the chair. In this position participants performed 30 maximal voluntary eccentric contractions (MVEC) on the isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY), consisting of 5 sets and 6 repetitions. This contraction was through the final 90° of motion from a fully extended position at a velocity of 30°s⁻¹, which meant that each contraction took 3 s to complete. Between each repetition participants were given 10 s to passively return their forearm to the starting position before the subsequent repetition and 2 min of passive recovery was given between each set⁴⁴.

Figure 5. Biodex set-up used for the exercise intervention along with strength and power measures.

Recovery Measures

Swelling: After EIMD muscle swelling tends to increase with the amount of damage observed. To measure edema in the upper arm muscle thickness was measured from three transverse ultrasound (LOGIQ 7, General Electronic, USA) images which were recorded using a 5.5 cm linear transducer (ML6-15, General Electronics, USA) (see Figure 7). To standardize the measurement location, a point was marked 50% of the length between the acromion of the scapula and olecranon process of the ulna on the anterior surface of the arm. Indelible ink marker was used to mark the spot and then gave it to the participant go over in the subsequent days to ensure the same anatomical position every time.

As an additional measure of swelling, circumference measure was taken using a calibrated tape measure which was taken at the first point listed above. Once the standard 60" Gulick tape measure (Richardson, Frankfort, IL) was loosely around the arm at the correct point it was then recoiled with 4-ounce tension to give an accurate measurement in cm. During all circumference measures participants were told to relax their arm with the arm resting on their side but not in contact with the body.

Figure 6. Ultrasound measurements of intramuscular swelling

Range of motion (ROM): After EIMD ROM tends to decrease because of damage to the sarcomeres or tendons of the muscle. To measure the change in ROM measurements of maximal active and passive arm position were recorded using a standard True- Angle goniometer (Quint Graphics, NJ). Passive range of motion was tested by the participant standing and letting their arm relax beside their body. The

goniometer was then placed on the lateral epicondyle with the proximal arm on the mid deltoid and the distal arm in the middle of the wrist as the arm rests in a semi-pronated position. Active range of motion was taken with the goniometer placed on the lateral epicondyle, the top arm on the mid-deltoid and the bottom arm placed on the lateral side of the wrist (radius). During the active range of motion, the participants arm was placed in a supinated position for all measures. Indelible ink marker was used to mark the spot during first testing session and then gave it to the participants to go over in the subsequent days to ensure that the same anatomical placements were used every time. ROM was defined as the angular change between maximal elbow flexion and extension. This procedure is commonly cited in the literature as a measurement of ROM in the elbow flexor muscles ²⁴.

Figure 7. Passive extension (left) and active flexion (right)

Perceived soreness: DOMS is usually measured using subjective scales and tend to increase after EIMD. To measure muscle soreness, we used three separate visual analogue scales (VAS), in which the participant drew a line on a blank 10 cm chart rating their pain from no pain at all to the worst possible pain (see Figure 10). The first VAS scale was in a resting position on the Biodex with the upper arm rested on the pad at 45° shoulder flexion with the arm fully extended (see Figure 11)¹⁷. The second measurement looked at the arm in motion with the arm in the same position as the first one but this time they performed 2 controlled bicep curls with zero resistance to replicate movement of the muscle¹⁸. The final VAS was used for soreness of touch / palpation. In this test using a 1 cm² transducer was used to apply 1.5 kg of force (kgf) to the bicep using an algometer (Force Ten FDC Digital Force Gage, Wagner Instruments, Greenwich CT: 6). The anatomical position used was the same as stated for the circumference measure. The 1.5 kgf used in this test was determined by pilot testing of 5 participants where the force was bearable, but they could detect a small amount of discomfort. The force was applied at constant rate of ~0.5 kgf by a trained researcher (see Figure 12). Lastly, the algometer was used again to determine pain to pressure threshold (PPT). Pressure was applied at a rate of ~0.5 kgf per second and the participants were instructed to say stop when they no longer felt pressure and started to feel pain, in which the pressure was stopped, and the number recorded (kgf).

Figure 8. Resting, motion and palpation VAS

Strength: Muscular strength tends to decrease after EIMD because of the disruption/displacement of the sarcomeres and neural function. To measure strength the Biodex dynamometer system pro 4 was used on the isometric setting to obtain maximal voluntary isometric contractions (MVIC). The participant was set up according to the elbow extension/flexion (seated) protocol explained in the Biodex manual and the intervention set-up (see Figure 6)⁴³. The arm was positioned at 90° elbow flexion using a goniometer. Before obtaining peak strength, the participant performed a warm-up which consisted 3 repetitions of 5 s isometric contractions in the fixed 90° position; first was at 50% of MVIC, second was at 70% MVIC and the last was at 90% MVIC with 1 min of rest between each repetition. After the warm-up the

participant did three, 5 s MVICs with 30 s rest in-between each attempt. The joint angle and rest time have been used in another study⁴⁵.

Power: Muscular power was measured to determine the loss in athletic performance. To measure power the participant was set up according to the elbow extension/flexion (seated) protocol explained in the Biodex manual and the intervention set-up (see Figure 6)⁴³, after which 30% of the participant's MVIC was calculated and inputted in to the isotonic setting on the Biodex dynamometer for resistance. The range of motion was set at 90° away from active flexion. The participant was asked to start in a flexed position and to lower the lever arm until it the dynamometer stopped (90°), once this happened the instructor yelled “pull” and the participant pulled the assigned weight back to its starting position as fast as possible. This was repeated 5 times and the peak power was recorded. To obtain peak power, torque was multiplied by velocity and the highest instantaneous power was recorded.

Power analysis: G-Power software was used to calculate the sample size of 10 participants through an *a priori* power analysis for a repeated measures ANOVA with two groups and 6 time points. The power analysis was performed for a difference in strength recovery with the expected effect size 0.4 which is based on previous literature and is considered which is a large statistical effect. Statistical power was set at 0.8 and the chance of a type 1 error was set at 0.05.

Statistical Analysis: Results were analyzed using SPSS 24 (IBM Corporation, Armonk, NY) and a 2 (treatment) by 6 (time) mixed ANOVA with repeated measures to identify the time effect from baseline. Furthermore, a 2 x 5 ANCOVA was used to find an overall interaction effect (time x intervention). Lastly a Bonferroni post-hoc was used to analyze time point differences for both an interaction and time effect. A Huynh Feldt correction used if sphericity was not met. Accepted significance was set at $p \leq 0.05$. All data are presented as means and standard deviations.

CHAPTER 4

FINDINGS

A total of 10 participants entered the study, in which they all completed the within subject design. Hydration was tested at the beginning of each testing day and the participant had to have a USG of ≤ 1.025 before testing began. There was no statistical difference in hydration of between conditions at any time point ($p = 0.072$).

Power: There was a significant time difference in 72 h in both conditions ($p < 0.001$). The timepoint comparison showed that there was a significant loss in both conditions up to 24 h, however, after 48 h there where was no significant change from baseline for power in the CwC condition ($p = 0.92$) (Figure. 9). Furthermore, there was a significant difference in interaction effect between the two conditions over 72 h ($p = 0.006$).

Figure 9. Relative power (left) and relative strength (right). Asterisks represent significant difference from baseline for CON; plus symbols represent significant difference from baseline for CwC; dollar sign represents significant difference between conditions.

Strength: There was a significant time difference in 72 h in both conditions ($p < 0.001$). More specifically, there was a significant drop in strength from baseline up to 24 h in both conditions (Figure. 9). However, the CwC condition had no significant difference to baseline at 48 h ($p = 1.0$) and 72 h ($p = 1.0$) while there was a loss of strength CON condition. Furthermore, there was a significant interaction effect over 72 h ($p = 0.004$) and a timepoint comparison at 24 h ($p = 0.046$), 48 h ($p = 0.02$), and 72 h ($p = 0.008$) there was an interaction effect between conditions (Figure. 9).

Swelling: Relative intramuscular swelling showed a significant time effect ($p < 0.001$) and interaction effect ($p = 0.05$) (after a Huynh Feldt correction was made for sphericity) over 72 h. Furthermore, CON intramuscular swelling was significantly increased from baseline immediately post exercise ($p = 0.042$) and at 72 h ($p = 0.03$) (Figure.10). Circumference measures using a tape measure did not show any significant changes from baseline in both conditions.

Figure 10. Relative intramuscular swelling. Asterisks represent significant difference from baseline for CON; plus symbols represent significant difference from baseline for CwC; dollar sign represents significant difference between conditions.

Perceived soreness: There was a significant time effect over 72 h for resting ($p = 0.004$), motion ($p < 0.001$), and palpation ($p = 0.017$); but not in PPT ($p = 0.640$). More specifically, for resting VAS, CON were significantly elevated to baseline ($p = 0.034$) at 72 h. Also, there were significant time effects in all timepoints in moving VAS in CON but only at 24 h for CwC ($p = 0.002$). There was no interaction effect in all VAS and PPT measures.

Range of motion: There was a significant time effect for ROM, flexion and extension ($p < 0.001$) but an interaction effect was only reported in flexion ($p < 0.001$) over 72 h. More specifically, loss in ROM when compared to baseline was seen at immediate post ($p < 0.001$) and 1 h ($p = 0.005$) for CON and only immediate post ($p = 0.032$) in CwC (Figure. 11). Active flexion was significantly different compared to baseline at immediate post ($p < 0.001$) and at 1 h ($p = 0.013$) in the CON only.

Figure 11. Range of motion. *Asterisks* represent significant difference from baseline for CON; *plus symbols* represent significant difference from baseline for CwC; *dollar sign* represents significant difference between conditions.

Lactate: In the CON condition there was significant differences from baseline ($p = 0.004$) and when compared to CwC immediately post exercise. Both conditions returned close to baseline at 1 h.

Figure 12. Blood lactate. *Asterisks* represent significant difference from baseline for CON; *plus symbols* represent significant difference from baseline for CwC; *dollar sign* represents significant difference between conditions.

CHAPTER 5

DISCUSSION

These results present, for the first time, the effect of contrast with compression (CwC) therapy on recovery from eccentric exercise in recreationally trained men. Our results indicate that when compared to a passive control, three bouts of 10 min of CwC can significantly increase recovery rate in the elbow flexor muscles. Within 72 h, power, strength, and swelling measures showed significant interaction effect of recovery when CwC was used compared to CON. Moreover, this supports our primary hypothesis that CwC will lead to greater recovery in muscular performance measures. Our secondary hypothesis was partially accepted as swelling and active flexion showed significance between conditions, however, all perceived soreness measures, ROM, and passive extension did not.

Power and strength: In the present study, there were significant changes observed between conditions for both power and strength over the 72 h observation period. Furthermore, power and strength loss were seen in both conditions up to 24 h. At 48 h power was still significantly lower in CON but not in CwC which indicates that power was regained at this timepoint. Strength measures showed that at 24 h, 48 h, and 72 h CwC showed faster recovery of strength when compared to CON. Also, after the post exercise intervention we saw a drop off in peak power and strength in CwC (45.4 ± 15.5 and $73.9 \pm 15.4\%$) and CON ($51.9 \pm 21.7\%$ and $63.4\% \pm 16.3\%$) of their max

respectively. This is in-line with the 65% of max strength was seen post muscle damaging exercise in a previous study using the same protocol and population⁴⁴. While this is the first study that tracked the rate of recovery after use of CwC therapy, several previous studies have independently investigated recovery after CWT and compression therapy. A meta-analysis by Bieuzen *et al.*⁷ compared CWT to a passive CON and showed strength and power had significantly lower changes from baseline. Six studies measured strength at 6, 24, 48, 72, and 96 h after EIMD and reported that groups that received some kind of CWT had less of a loss in strength in all time points except 72 h. Three studies used change from baseline scores for power and reported less of a loss in power at 24, 48 and 72 h. Vaile *et al.*²² reported that when using 30% of one's isometric strength to perform a squat jump, less of a loss in power is observed at 24 and 48 h when using 15 min of CWT compared to CON ($p < 0.006$).

Compression therapy has typically been investigated when used as a low compression garment or sleeve for long periods of time post exercise or during the exercise. In-line with these results a meta-analysis by Hill *et al.*⁴⁶ showed that this can be effective in reducing the loss of strength (Hedges' $g = 0.462$, CI 0.221-0.703, $p < 0.001$) and power (Hedges' $g = 0.487$, CI 0.267-0.707, $p < 0.001$) at 24, 48 and 72 h. The overall Hedges' g of 0.49 and 0.44 for strength and power indicate that 69% and 66%, respectively, of the population will experience accelerated recovery of strength and power when using a compression garment. More specifically, when combining cold and compression therapy (20 PSI) for 20 min bouts immediate post, 24 and 48 h, DuPont *et al.*⁴ saw a reduced loss in power at 24 and 48 h which shows that combining

those two modalities could be more efficient, however this is the only study we found investing this modality.

Decreased strength and power could be attributed to a disruption in the excitation-contraction coupling which means that's less calcium is released per action potential⁴⁷. Decreased strength could also be due to a change in the length tension relationship or to overstretched and misaligned sarcomeres that would provide a fewer number of cross-bridges^{11,16}. Lastly, as these mechanisms are damaged it may cause some neural factors to inhibit full stimulation of the muscle to protect it from further damage, this is called central modulation¹⁶. In this study we believe that the contrast offered a pumping action in the vessels which helped increase blood flow to clear metabolites, repair muscle and slow down the metabolic process^{7,21}. This may be amplified using compression which reduces the inflammatory response which in turn attenuates further ultrastructural damage and restore central factors that result in reduced voluntary activation².

Swelling: In the present study, there were significant changes observed between conditions in intramuscular swelling using ultrasound but not in circumference measures. It is important to note that ultrasound is the “gold standard” when measuring muscular swelling as it gives a clearer picture of the muscle and allows for more accurate readings compared to a tape measure. These two results may not correlate due to the tester error or due to small amounts of swelling in bicep brachii was hard to detect by using the whole circumference of the arm. Ultrasound swelling

has been used in a previous study¹⁴ but due to the cost of this measure several previous studies have used circumference measures^{1,18}.

In line with our results Vaile *et al.*¹⁸ showed similar findings when using CWT for 14 min once a day at post, 24, 48, and 72 h. After a muscle damaging protocol, mid-thigh girth as measured through circumference, was significantly lower in 24, 48, 72 h ($p < 0.01$). Furthermore, Winke *et al.*¹⁷ compared wearing a mild compression sleeve for 108 h to 20 min per day of PC in the upper arm. They reported that the magnitude swelling in the PC group was significantly lower ($p = 0.012$) over 108 h, which suggests intermittent compression at higher intensities could be more beneficial.

Due to the necrosis of some muscle fibers during repeated eccentric contractions there is an inflammatory response consisting of leukocytes and neutrophils that cause edema⁹. The CwC machine reduced the inflammation by compressing the upper arm which allowed smaller changes in osmotic pressure which diminishes fluid shifts to the interstitial space therefore causing less edema⁶. Again, this process seemed to be amplified by CWT which allowed an increased blood flow to clear metabolites, repair muscle and slowing down the metabolic process caused by the pumping effect during vasodilation and vasoconstriction^{7,21}.

Range of Motion: The exercise intervention caused significant reduction in ROM, active flexion and passive extension. However, in the present study, there were no significant changes observed between conditions for ROM and extension, but there

were significant changes in flexion. The CON condition showed reduced ROM at 1 h but not in the CwC which shows that CwC may have short term benefits. It is evident in Figure. 11 that there was a reduction on ROM in both conditions and that CwC suggests closer to baseline scores, but more research needs to be done to see if there could be significant findings.

In line with these results Kraemer *et al.*¹⁵ reported no significance in extension when the participants wore a compressive sleeve (10 mm Hg) for 108 h after an eccentric workout. Conversely, range of motion in the elbow flexor muscles had a significant main effect over 108 h in both elbow extension ($p = 0.005$) and elbow flexion ($p = 0.002$) when using PC once a day for 20 min over 5 days compared to continuous slight sleeve compression¹⁷. This shows that intermittent PC may offer superior benefits to range of motion however this was not back up with the combination on contrast and compression and requires more exploration.

Possible explanation for the significant interaction effect during elbow flexion reported in this study may be due to the reduced swelling of the bicep offered by CwC, limiting the amount of flexion possible by the participant. A loss in range of motion may also be due to the volume change of the muscle which adds increased tension on the connective tissue or damage to the connective tissue itself^{10,11}. Other potential mechanisms for lower resting extension may be because of an increased calcium concentration in the damaged muscle that causes a low intense contraction¹².

Perceived soreness and PPT: In the present study, there was a significant time effect for all perceived soreness measures but not PPT. We took a comprehensive approach and included resting, motion, palpation and PPT to analyze soreness, which are all used in current literature but are rarely seen together. The VAS and PPT differ as a VAS informs us of the severity of the pain felt after a set stimulus but PPT shows us the level of palpation a participant starts to feel pain.

In line with our result Vaile *et al.*²² reported no difference between CWT and CON when subjects rated perceived soreness using VAS in a 72 h time frame. Conversely, CWT did show significance in all time points compared to CON in a meta-analysis at 6 h (6 trials), 24 h (13 trials), 48 h (10 trials) and 72 h (5 trials)⁷. As reported pain is a subjective measure that has a large degree of inter-person and inter-day variability, larger samples sizes (such as those of the meta-analysis) may be needed compared to other physiologically based measures used in the present study. When comparing PC to CON Winke *et al.*¹⁷ reported no significance in palpation measures, but they did find significance using VAS during elbow extension in a rested position ($p \leq 0.05$)⁷. Also DuPont *et al.*⁴ showed that cryocompression when used in recreationally trained athletes for 20 min, post, 24, and 48 h after exercise showed a main effect ($p \leq 0.05$) in general soreness using a VAS over 48 h after eccentric exercise which leaves room for future exploration.

Cold water therapy appears to lower pain sensation through both an analgesic effect and reduced nerve conduction velocity. Also reducing edema through compression

and CWT can reduce the pressure on pain receptors in the muscle^{6,25}. In summary, our study does not back these theories and other studies up and this could be due to the subjective nature of VAS and the day to day variation.

Limitations: This study had several limitations including a non-athletic population. The participants in the present were recreationally trained in a variety of activities. As the machine is intended to enhance muscular recovery in an athletic population it would be better served to do this study using the intended target population. However, controlling for exercise in an athletic population can be difficult due to their rigorous training and games schedules. Furthermore, muscle damage does not change between individuals and therefore we were still able to monitor recovery in our lab-based intervention. This study could have included a muscle damaging measure such as CK to measure the amount of damage in the muscle and track changes; CK has been used in multiple studies^{2,4,15,48}. Also, compression was not measured in the CwC cuff, which makes it hard to draw conclusion as to how much pressure is needed to see a positive effect in performance and swelling measures. However, the external validity of this compression was still present as demonstrated by the strength, power and swelling measurements. Lastly, palpation VAS was administered at the midpoint between the acromion process and the olecranon process, which was meant to represent the location of the muscle belly. However, previous studies have reported that point tenderness is greatest at the myotendinous junction rather than the muscle belly¹², therefore a location closer to the elbow creases may have yielded clearer results in perceived soreness.

Conclusion: This study was the first to examine the effects of combining contrast with compression therapy (CwC) as a post exercise recovery modality. When CwC was used at three time points (immediately, 24 and 48 h post exercise) statistical analysis demonstrated improved recovery over at 72 h in strength, power and swelling. This information would benefit sports team coaches and athletic trainers in their attempt to decrease recovery time between training and game-play to maintain peak athletic performance. Future research should seek to investigate doing this in an athletic population, compare CwC to other recovery techniques, or measuring the amount of compression needed to cause an effect with contrast therapy. This study had many strengths such as the controls, a crossover design, and the use of multiple variables to measure muscle damage accurately. Therefore, CwC should be considered as a post exercise recovery modality for increased recovery after an intense exercise bout.

APPENDICES

Appendix I

Consent Form for Research

We hope that you consider taking part in our study examining how contrast with compression therapy affects recovery from a bout of exercise. We believe that this study (detailed below) has potential to improve how sports medicine professionals treat their clients in order to help them recover from exercise and/or injury.

STUDY TITLE – The effects of contrast therapy with compression on exercise recovery.

PRINCIPAL INVESTIGATOR

Principal Investigator: Jacob Earp, Ph.D.
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KEY INFORMATION

Important information to know about this research study:

- The purpose of the study is to determine if contrast with compression (CwC) therapy improves an individual's recovery after a bout of exercise.
- If you choose to participate, you will be asked to sign this informed consent document and then complete a total of 8 days of testing over a 3-week period. The anticipated total time commitment for this study is ~8 hr.
- The first 4 days of testing will be used to test condition #1 (either CwC therapy or no therapy) while the last 4 days of testing will be used to test condition #2 (either CwC therapy or no therapy). The order of the conditions that you receive will be randomly assigned, but you will complete both conditions.
- In the first week of testing you will be asked to attend 4 days of testing each separated by 24 hr.
 - Day 1 – Baseline testing & exercise bout: ~2 hours.
 - Days 2-4 – Follow-up / recovery testing: ~30-45 min each day.
- Then you will be given 3-7 days of recovery before repeated these four days of testing:
 - Day 5 – Baseline testing & exercise bout: ~2 hours.

- Days 2-4 – Follow-up / recovery testing: ~30-45 min each day.
- Risks or discomforts from this research include moderate muscle soreness from performing eccentric muscular contractions of the elbow flexor muscles.
- The study will be used to determine whether contrast with compression therapy is a good alternative to other recovery modalities on the market.
- You will be provided a copy of this consent form.
- Taking part in this research project is voluntary. You don't have to participate and you can stop it any time.

INVITATION

You are invited to take part in this research study. The information in this form is meant to help you decide whether or not to participate. If you have any questions, please ask.

Why are you being asked to be in this research study?

You are being asked to be in this study because you may be interested in participating in research related to kinesiology, physical therapy or sports medicine. To take part you must be between the ages of 18-35, male, and currently free from any elbow flexor injury in the past 6 months.

What is the reason for doing this research study?

There are many recovery methods employed in both athletic and physical therapy departments, which vary in degree of effectiveness. Combining contrast therapy with compression therapy may offer compounding benefits to recovery that provides a potent stimulus for recovery.

What will be done during this research study?

After signing this informed consent document you will be asked to schedule your 8 days of testing over a 3-week period (this should take ~ 15 min).

All participants will complete an exercise day and 3 days of recovery testing after receiving contrast with compression (CwC) therapy as well as a separate exercise day and 3 days of recovery testing in which no recovery therapy is provided. However, the order of these two conditions will be randomly assigned to each participant. Details of each session are provided below:

Days 1 & 5 – Baseline Testing, Exercise Bout and Post-Exercise Testing:

On this day you will complete baseline testing which will consist of a range of motion test as well ultrasound measures of your biceps muscle, blood measures taken using the finger stick method, soreness measures using various scales and elbow flexor strength and power tests. You will then complete a bout of elbow flexor exercise using specialized equipment (e.g. 6 sets of 5 repetitions of eccentric / lower arm curls). Finally you will then repeat the testing you performed at baseline immediately after and 1 hr after the exercise. On the day that you are assigned to the CwC condition you will also receive 15 min of CwC prior to the 1 hr post testing. Your estimated time commitment for these days are ~2 hr each day.

Days 2, 3, 4 & Days 6, 7 & 8 – Recovery Testing

You will be asked to complete follow-up testing 24, 48 and 72 hr after the each exercise bout (Day 1 & Day 5) in order to monitor your recovery from the exercise. In each session you will be asked to repeat the same testing that you performed before the exercise, including measures of range of motion, ultrasound of your biceps muscle, blood measures taken using the finger stick method, soreness measures using various scales and elbow flexor strength and power tests. Each of these sessions should take ~ 30 min. Additionally, when assigned to the CwC condition additional CwC therapy sessions will be provided at 24 & 48 hr post-exercise

How will my data be used?

Your data will coded so that you cannot be identified and results from analysis of your data will presented at scientific conferences and published in scientific journal without any individual identifiers.

What are the possible risks of being in this research study?

There are minimal risks to you from being in this research study but you may experience delayed onset muscle soreness after the exercise intervention but this should not affect your daily living.

What are the possible benefits to you?

You are not expected to get any benefit from being in this study.

What are the possible benefits to other people?

The results from this study will provide information that can potentially be used to improve the effectiveness of recovery programs that are designed to help people to recovery from exercise or injury.

What are the alternatives to being in this research study?

Instead of being in this research study you can decide not to take part in this study without any repercussions.

What will being in this research study cost you?

There is no cost to you to be in this research study.

Will you be compensated for being in this research study?

You will receive financial compensation of \$150 in gift cards after completion of the study.

What should you do if you have a problem during this research study?

Your welfare is the major concern of every member of the research team. If you have a problem as a direct result of being in this study, you should immediately contact one of the people listed at the beginning of this consent form.

How will information about you be protected?

Reasonable steps will be taken to protect your privacy and the confidentiality of your study data. *The data will be stored electronically through a secure server and will only be seen by the research team during the study. The only persons who will have access to your research records are the study personnel, the Institutional Review Board (IRB), and any other person, agency, or sponsor as required by law. The information from this study may be published in scientific journals or presented at scientific meetings but the data will be reported as group or summarized data and your identity will be kept strictly confidential.*

What are your rights as a research subject?

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study.

For study related questions, please contact the investigator listed at the beginning of this form.

For questions concerning your rights or complaints about the research contact the Institutional Review Board (IRB) or Vice President for Research and Economic Development:

- IRB: (401) 874-4328 / researchintegrity@etal.uri.edu.
- Vice President for Research and Economic Development: at (401) 874-4576

What will happen if you decide not to be in this research study or decide to stop participating once you start?

You can decide not to be in this research study, or you can stop being in this research study (“withdraw”) at any time before, during, or after the research begins for any reason. Deciding not to be in this research study or deciding to withdraw will not affect your relationship with the investigator or with the University of Rhode Island (list others as applicable).

You will not lose any benefits to which you are entitled.

Documentation of informed consent

You are voluntarily making a decision whether or not to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered and (4) you have decided to be in the research study. You will be given a copy of this consent form to keep.

Participant Name:

(Name of Participant: Please print)

Participant Signature:

Signature of Research Participant

Date

Investigator certification:

My signature certifies that all elements of informed consent described on this consent form have been explained fully to the subject. In my judgment, the participant possesses the capacity to give informed consent to participate in this research and is voluntarily and knowingly giving informed consent to participate.

Signature of Person Obtaining Consent

Date

Appendix II

Data Collection Sheet for CwC Study

Subject number: _____ Date: _____ Time: _____

Test day (circle one): Pre Post 1H 24H 48H
72H

Intervention (circle one): Control Experiment

The subject has refrained from exercise for the duration of this study. Yes _____
No _____

Subject Descriptor (first visit only):

Exercise history:

Type	Frequency	Intensity

DOB: _____

Age: _____

Height: _____

Weight: _____

BIA body fat percent: _____

Working arm lean mass %: _____ Lbs: _____ Working arm side: Right
Left

Testing:

Hydration level: _____

Blood Measures:

Creatine Kinase levels: _____ IU/L

Lactate level: _____ mmol

Ultrasound measures

Cross sectional swelling: 1: _____ 2: _____ 3: _____

Average: _____

Transverse swelling: 1: _____ 2: _____ 3: _____

Average: _____

Range of motion

Passive extension: _____ degrees

Active flexion: _____ degrees

Circumference measures (cm): _____

VAS Scale

Resting: _____

Motion: _____

1.5kgf algometer: _____

PPT (KGF):_____

Biodex measures

Position of chair: _____ Height of chair: _____ Pad position: _____

Arm lever length: _____ Position of dynamometer: _____ Back of the seat: _____

Height of dynamometer: _____

Isometric strength:

	Rep 1	Rep 2	Rep 3	Peak
Peak torque				

30% of MVIC:_____

Isotonic:

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Peak
Peak Power						

Notes:

[illegible]

Appendix III

Subject Randomization

Visit one

Subject	Arm	Intervention/control
1	Dominant	Control
2	Dominant	Intervention
3	Non-dominant	Control
4	Non-dominant	Intervention
5	Dominant	Control
6	Dominant	Intervention
7	Non-dominant	Control
8	Non-dominant	Intervention
9	Dominant	Control
10	Non dominant	Intervention

Visit two

Subject	Arm	Intervention/control
1	Non-Dominant	Intervention
2	Non-Dominant	Control
3	Dominant	Intervention
4	Dominant	Control
5	Non-dominant	Intervention
6	Non-dominant	Control
7	Dominant	Intervention
8	Dominant	Control
9	Non-dominant	Intervention
10	Dominant	Control

Appendix IV

Flyer

KINESIOLOGY RESEARCH OPPORTUNITY!!

ARE YOU A MALE AGED BETWEEN 18 AND 35?

We are looking for subjects to participate in our study on muscular recovery using a NEW contrast and compression machine.

You may be eligible to join if you are:

- A relatively healthy male between the ages of 18 and 35.
- Have had no upper extremity injuries in the past 6 months.
- Willing to attend all the exercise and testing procedures on URI campus.

What's Involved?

- You'll be asked to perform 2 upper body workouts and have your recovery tracked for 3 days after each workout

Time Commitment?

- 8 days of testing over a period of 3 weeks (totaling ~ 8 hours)

Financial Compensation?

- You'll receive \$150 in gift cards for completion of the study

Interested?

- **Contact:** Dr. Earp: uricwc@gmail.com for more information

Principal Investigator: Jacob Earp, PhD, CSCS – Dept. of Kinesiology @ URI

This research has been approved by The University of Rhode Island Institutional Review Board.

Appendix V

Table 1. Anthropometric measures (mean $\pm$ SD)

Participants (N)	10
Age (years)	21.3 $\pm$2.1
Height (cm)	182.1 $\pm$8.5
Weight (kg)	88.0 $\pm$19.5
Body fat (%)	17.2 $\pm$7.0
Left arm lean mass (lbs)	9.02 $\pm$1.50
Right arm lean mass (lbs)	9.13 $\pm$1.61
CON lean mass (lbs)	9.05$\pm$1.60
CwC lean mass (lbs)	9.09$\pm$1.50

Appendix VI

Table 2. All data points (mean on the top and SD below)

Variable	Control						CMC						Interaction
	Pre	Post	1 h	24 h	48 h	72 h	Pre	Post	1 h	24 h	48 h	72 h	Time Effect effect
Relative Swelling	100.00	110.81	106.29	110.64	113.45	114.32	100.00	106.82	102.69	106.03	105.49	104.680*	0.05*
	0.00	8.72	9.42	11.14	14.72	15.62	0.00	12.65	14.42	11.37	11.57	12.53	
Relative ROM	100.00	83.88	85.11	90.10	91.71	89.96	100.00	90.30	91.99	92.40	93.68	94.680*	0.35
	0.00	11.92	13.47	11.47	13.98	9.25	0.00	4.03	5.46	7.08	7.20	9.92	
Relative Circumference	100.00	104.54	104.01	104.16	102.66	104.76	100.00	98.90	98.36	98.34	97.94	97.66	0.893
	0.00	8.15	8.48	8.56	8.11	8.86	0.00	8.87	9.50	8.93	8.89	8.68	0.34
Pasting	0.03	0.44	0.29	0.56	0.82	0.70	0.07	0.64	0.22	0.52	0.56	0.390.004*	0.37
	0.05	0.53	0.34	0.74	1.31	0.79	0.10	0.65	0.25	0.55	0.55	0.42	
Motion	0.04	1.00	0.73	1.18	2.12	1.57	0.07	0.86	0.34	1.03	1.14	0.680*	0.08
	0.06	0.63	0.55	0.79	1.58	1.28	0.12	0.52	0.32	0.77	0.68	0.79	
Relaxation	0.46	0.86	0.44	1.06	1.21	1.08	0.29	0.89	0.66	1.00	1.11	0.620.017*	0.63
	0.65	0.72	0.34	1.29	1.26	1.31	0.32	0.63	0.44	0.76	0.68	0.58	
PPT	2.66	2.90	2.38	2.40	2.28	2.49	2.83	2.53	2.62	2.54	2.53	2.84	0.64
	0.95	2.27	1.42	1.06	0.98	1.02	1.61	1.35	1.45	1.70	1.35	1.70	0.56
Relative Strength	100.00	63.37	65.71	63.09	66.57	68.92	100.00	73.85	78.81	78.48	87.71	93.950*	0.004*
	0.00	16.27	18.33	16.30	19.06	23.76	0.00	15.38	20.90	18.99	24.30	18.20	
Relative Power	100.00	51.94	49.88	50.37	58.22	64.28	100.00	45.36	55.29	64.35	70.02	87.700*	0.006*
	0.00	21.68	26.15	36.40	32.67	36.86	0.00	15.54	26.84	26.39	30.76	34.96	

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