

ESTIMATING CONTRIBUTIONS OF COLD WATER
IMMERSION TO RECOVERY FROM EXERCISE

By

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Title of Study: ESTIMATING CONTRIBUTIONS OF COLD WATER IMMERSION
TO RECOVERY FROM EXERCISE

Major Field: HEALTH & HUMAN PERFORMANCE

PURPOSE: Investigate the efficacy of cold water immersion (CWI) for alleviating perceived soreness and estimate its contributions to muscle damage recovery after exercise. **METHODS:** Fourteen (mean age=22.4 years, height= 1.81m, mass=88.38kg) males with history of resistance training (defined by at participation in 3 resistance training sessions a week) visited the lab on 2 occasions, separated by 7 days. First visit involved familiarization protocol with the Biodex 3 dynamometer. Participants performed isometric maximal voluntary contractions (MVCs) at a fixed joint angle of 120° to determine peak torque of the knee extensors before the exercise protocol (PRE), immediate post-exercise protocol (IPP), immediate post-treatment (IPT), and fifteen minutes post-treatment (15minPost, treatment visit only). The eccentric exercise protocol (10 repetitions/set at 60°/s) designed to induce muscle damage was performed on right leg only during treatment and control visit (randomized visits). Control involved sitting quietly in a chair in the research laboratory for 10 minutes. The treatment condition involved CWI up to the iliac crest in 10°C (50°F) water for 5 minutes. Perceived soreness was measured using 100-point analog scale. Soreness was measured during both visits at 5 time points (PRE, IPP, IPT, 24HrPost, 48HrPost). Separate 2-way mixed factorial ANOVAs were performed for each dependent variable. An alpha level of $p \leq 0.05$ was utilized to determine statistical significance. **RESULTS:** Significant visit x time interaction found for exercise leg MVC torque [$F(2,26)=3.463, p=0.046$]. MVC torque IPT treatment significantly lower than PRE treatment [$p=0.045$]. Significant effect for time found for MVC during treatment visit exercise leg [$F(2,26) = 4.471, p=0.021$]. Significant interaction found between condition and time for exercise leg treatment visit MVC [$F(2,26)= 3.463, p=0.046$]. There was no significant visit x time interaction for control leg MVC [$F(2,26)=1.086, p=0.352$]. No significant main effect for time of control leg MVC [$F(2,26)= 0.871, p=0.430$]. A significant main effect for condition was found for control leg MVC [$F(1,13)=6.401, p=0.025$]. Significant difference found between control and treatment visit perceived soreness at 24HrPost for exercise leg [$p=0.028$]. **CONCLUSIONS:** CWI did not have an effect on peak torque production, but significantly reduced perceived soreness 24HrPost treatment on the exercise leg compared to control visit.

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
II. METHODOLOGY	3
Purpose.....	3
Subjects.....	4
Exercise Procedures	5
Exercise Protocol	6
CWI Treatment	6
Perceived Soreness.....	7
Statistical Analyses	8
III. FINDINGS	9
MVC Peak Torque	9
Perceived Soreness.....	12
IV. DISCUSSION.....	15
Introduction.....	15
Primary Hypothesis.....	15
Secondary Hypothesis.....	17
Tertiary Hypothesis.....	19
Primary Research Question.....	19
Secondary Research Question.....	20
Practical Applications	21

	Page
REFERENCES	22
APPENDICES	27
A. Assumptions.....	27
B. Limitations of the Study.....	27
C. Significance of the Study	27
D. Definition of Terms.....	28
E. Review of the Literature.....	29
Introduction.....	29
Muscle Damage	29
CWI & Biomarkers of Muscle Damage.....	38
Perceived Soreness.....	45
Exercise Performance	51
F. IRB Approval Letter	57

LIST OF FIGURES

Figure	Page
1.....	4
2.....	7
3.....	9
4.....	10
5.....	11
6.....	12
7.....	13
8.....	14

CHAPTER I

INTRODUCTION

Cold water immersion (CWI) is an often utilized modality for alleviating muscular soreness following intense exercise, sport practice and sport competition. Intense exercise brings about many physiological processes including DOMS (delayed onset muscle soreness) which can affect athletes significantly (Croisier et al., 2003). DOMS can be further amplified by intense practice sessions, weightlifting, or competitive events (Croisier et al., 2003). After exercise or competition, many times athletes complain of soreness, muscle fatigue and muscular tightness (Croisier et al., 2003). Many modalities and methods have been used to help athlete's recover from intense exercise, practice and actual competitive events. Immersion protocols in water temperatures ranging from 5°C to as warm as 38°C have been previously used (Santos et al., 2012; Elias et al., 2013). Researchers have also utilized cold water therapy using immersion in cold water, and mixed water therapy using cold water alternated with warm water in a variety of time point and duration of immersion protocols. Length of immersion is also a topic of debate within the research, with studies

ranging from 1 minute of duration to as long as 20 minutes of continuous immersion (Robey et al., 2009; Minett et al., 2014). Variables in previous studies that were used for determining recovery from perceived fatigue, soreness, and DOMS include: creatine kinase levels (CK), C-reactive protein levels (CRP), myoglobin levels, maximal voluntary contraction (MVC), and ratings of perceived soreness (Byrne & Eston, 2002; Robey, Dawson, Goodman & Beilby, 2009; Skurvydas et al., 2006; Ascensao, Leite, Rebelo, Magalhaes & Magalhaes, 2011; Brophy-Williams, Landers & Wallman, 2011; Jajtner et al., 2015; Minett et al., 2014; Montgomery et al., 2008; Bailey et al., 2007; Goodall & Howatson, 2008). These methods were intended to help the athlete recover faster in order to help them maintain or even improve athletic performance in their respective events or sports (Cochrane, 2004). Athletes that can compete or train at a high level, then suffer from reduced performance due to the combined effects of muscular fatigue/soreness, neuromuscular fatigue and even possible injury, are at a disadvantage. It is only natural that those who participate in sports or exercise desire to find a method for giving them a means to improve their ability to train and compete (Brophy-Williams, Landers & Wallman, 2011).

The goal of this study was to determine the effects of CWI for alleviating perceived soreness and markers of muscle damage as well as to estimate the contributions of CWI to recovery after exercise. The exercise protocol was only conducted on the dominant leg, also to examine the contralateral effects of CWI on MVC and perceived soreness.

The primary hypothesis was that soreness scores were expected to be higher immediately after the control than the CWI treatment. The secondary hypothesis was that MVC torque levels would be significantly higher after CWI than control for both the treatment and control leg. The tertiary hypothesis was soreness would be less during the treatment visit compared to control at *24HrPost* and *48HrPost* for both treatment and control leg.

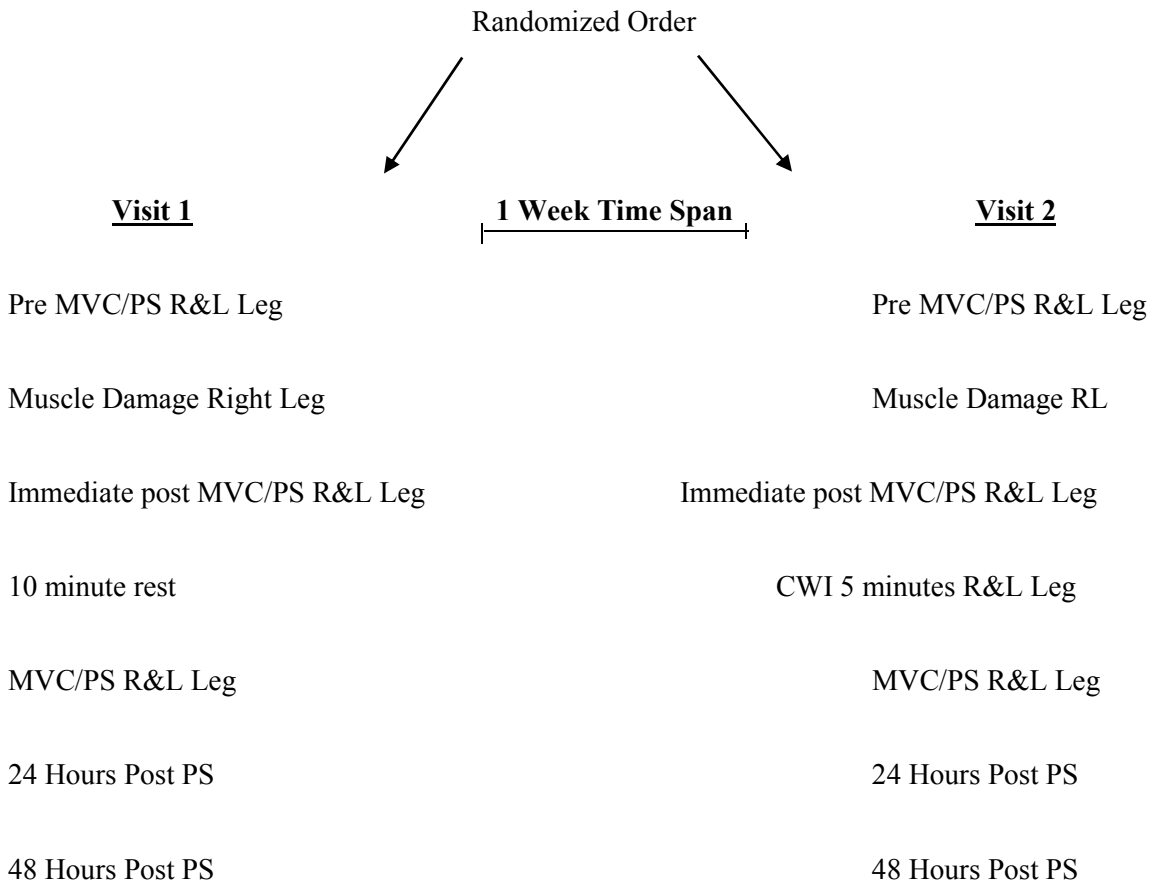
CHAPTER II

METHODS

Purpose and Study Design

The purpose of this study was to investigate the efficacy of CWI for alleviating perceived soreness and to estimate its contributions to muscle damage recovery after exercise. To examine the effects of the CWI, a cross-over design was utilized for which each participant performed every condition; CWI and a control. An eccentric exercise protocol was used to induce temporary muscle damage of the right leg knee extensors. During one visit the participant immersed their lower body into a cold-water ice bath for 5 minutes. During the other visit, the participant rested (control condition) for the same amount of time in place of the CWI. The order of the 2 visits was randomized and took place at least 1 week apart to allow for full muscle recovery. Maximal strength was measured before and after the eccentric protocol, immediately after the CWI or rest, and again 15 minutes post for the CWI treatment only. Perceived soreness was measured before and after the eccentric protocol, immediately after the CWI or rest, 15-minutes post CWI only, and again 24 hours & 48 hours later. The left leg (contralateral leg) was assessed at the same time points to determine the effect of just the CWI (without muscle damage). A flow chart of this protocol is seen in Figure 1 on the next page.

Fig. 1 Experimental design. *MVC* Maximal isometric voluntary contraction, *PS* Perceived soreness, *DL* Dominant leg, *PRE* Pre-exercise collection



Subjects

IRB approval was granted for the research study on Thursday, January 28, 2016, application no. GC1519. Fourteen males between the ages of 18-26 with a mean age of 22.4 years, average height 1.81m, and mean mass of 88.38kg. All subjects had a history of resistance training within the last 6 months. History of resistance training was defined by at least 3 resistance training sessions a week. These subjects were recruited because of their likely exposure to muscle damage, perceived soreness, exercise experience, and possible interest in improving exercise performance

via recovery treatment. A PAR-Q was distributed to each subject before the study began for the subject to fill out and endorse prior to activity. Written consent was obtained from each subject prior to study participation.

Exercise Procedures

Strength Testing

A standard warmup lasting for 5 minutes was conducted on a bicycle ergometer before the exercise protocol began. Each subject's maximal voluntary contraction (MVC) was determined for both the treatment (right) and control leg (left) pre-exercise, immediately post-exercise, immediately post-treatment, and again 15-minutes post treatment for the CWI visits only. A Biodex isokinetic dynamometer (Biodex Medical Systems, Inc. Shirley, New York, USA) was used to determine MVC for each subject. The dynamometer was set up according to the manufacturer's recommendations regarding exercise for knee extensors of the legs. Exercise protocol began with the subjects being adjusted properly to the dynamometer by aligning the lateral femoral condyle of the knee being exercised with the axis of rotation of the dynamometer arm. The subjects were strapped across the distal end of the femur to avoid the possibility of gaining leverage with the hip joint in the protocol. With a knee angle of 180° representing full extension, MVC was determined by setting the joint angle at 120°, locked in place, and marked to ensure consistency during subsequent testing and exercise sessions. Subjects were placed in a seated position and securely strapped to the test chair. Excessive movement of the upper body was limited by two cross-over shoulder harnesses and an abdominal belt. Prior to commencement of each test, the limb weight and moment acting upon the dynamometer power head were corrected for gravity. Three attempts at producing a single max contraction were allowed, with each repetition lasting approximately 3 seconds, with each repetition separated by at least a 60-second rest period. The highest peak torque generated from the three trials was recorded as MVC.

The torque signal was smoothed using a zero-shift moving average filter with a 25ms window. The torque output from the Biodex 3 was calibrated and converted to newton-meters. Peak torque was statistically determined by the highest 25ms peak during each contraction. Signals were sampled by a BioPac at 2000 samp./sec, saved, and analyzed with custom LabVIEW software (LabVIEW 8.5, National Instruments, Austin, TX, USA).

Exercise Protocol

The exercise protocol designed to induce muscle damage was conducted on the same isokinetic dynamometer used to measure MVC. After the warmup was conducted a familiarization protocol was performed on the dynamometer with the subjects before the exercise protocol began, which consisted of 1 set of five submaximal concentric contractions of the knee extensors throughout a constant range of motion. Concentric warmup was chosen and not eccentric warmup in order to avoid pre-exhaustion of the knee extensors before the eccentric exercise protocol. Sets of 10 eccentric repetitions each were performed until the participant could no longer reach 80% of their original MVC. Therefore, a 20% deficit was standardized for all participants during the exercise protocol portion of the study. Each set was separated by 2 minutes of rest recovery before the next eccentric set was conducted. The eccentric protocol range of motion was established by setting the toward ROM limit to 90° and the away limit ROM to 170° thus ensuring 80° ROM during repetitions for every subject. Immediate visual feedback was given from the Dynamometer computer screen regarding torque level and the investigator provided strong verbal encouragement in order to ensure maximum effort during each subject's exercise protocol session.

CWI Treatment

Following completion of the muscle damage protocol and the post-exercise tests, the CWI recovery visit involved the subject being seated up to the iliac crest in 10°C water for a

duration of 5 consecutive minutes. All 14 subjects within the study were able to last the entire duration of 5-minute immersion during their respective treatment visits. Water was kept at this temperature by adding crushed ice to the water when necessary. During the control visit each subject simply sat in a chair for 10 minutes.

Perceived Soreness

Subjects rated muscular soreness utilizing a perceived soreness pain scale developed by Burnett, Smith, Smeltzer and Burns (2010). In their study a 100 point analog scale was used that broke down into fourths at every 25 point mark with a pain level heading (Burnett et al., 2010). At the 0 point on the scale “no soreness” description was attached to that level, while at the 25 point level “mild pain” description was attached (Burnett et al., p.111, 2010). At the 50 point level “moderate pain” was the associated description, at the 75 point level “severe pain” was the description and lastly at the 100 point level on the scale “the worst pain you can imagine” was the associated description (Burnett et al., p.111, 2010). Fig .2 is an example of the measurement instrument and question.

Fig. 2

On a scale of 0 to 100 with 0 being “no pain” and 100 being “the worst pain you can imagine” what is your current level of perceived soreness of the muscles in your legs? (Please circle one of the choices or write your own perceived soreness pain level number)

0 25 50 75 100 or self-written number of perceived soreness _____

Statistical Analysis

Separate 2-way [(visit (CWI vs. Control) x time (Pre, Immediate post damage, Immediate post treatment, and 15 min. post treatment)] repeated measures ANOVAs were used to analyze both dependent variables (peak torque and perceived soreness) for each leg. Bonferonni pairwise comparisons were utilized for post-hoc analyses. An alpha level of 0.05 was used to determine statistical significance.

CHAPTER III

FINDINGS

MVC Torque

Group mean MVC's for the treatment leg for each time point and condition are shown below in Figure 3. A significant interaction was seen between condition and time for the exercised leg during the treatment visit [$F(2,26)= 3.463, p=0.046$]. A significant effect for time was seen within-subject effects for the exercised leg during the treatment visit [$F(2,26)=4.471, p=0.021$]. Pairwise comparisons for the exercised leg during treatment visit revealed that the Immediate Post Treatment (*IPT*) torque was significantly different from (*PRE*) [$p= 0.045$].

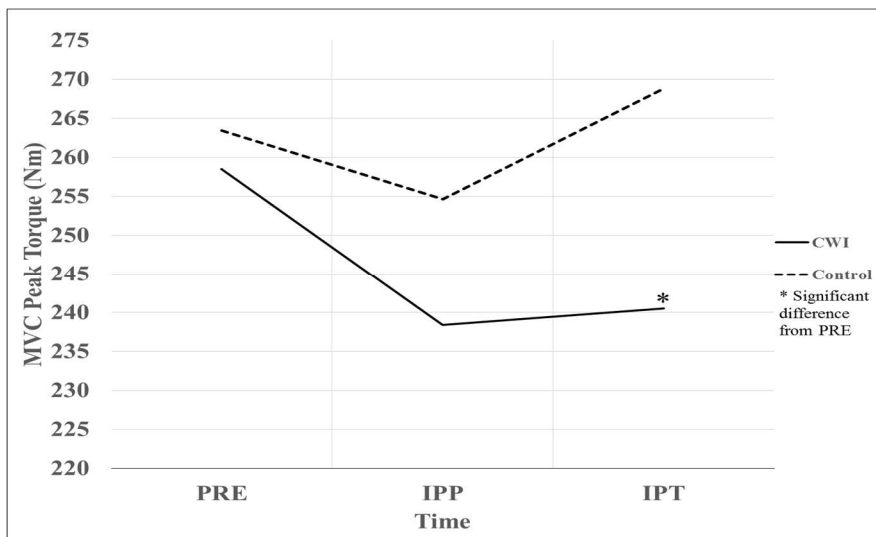
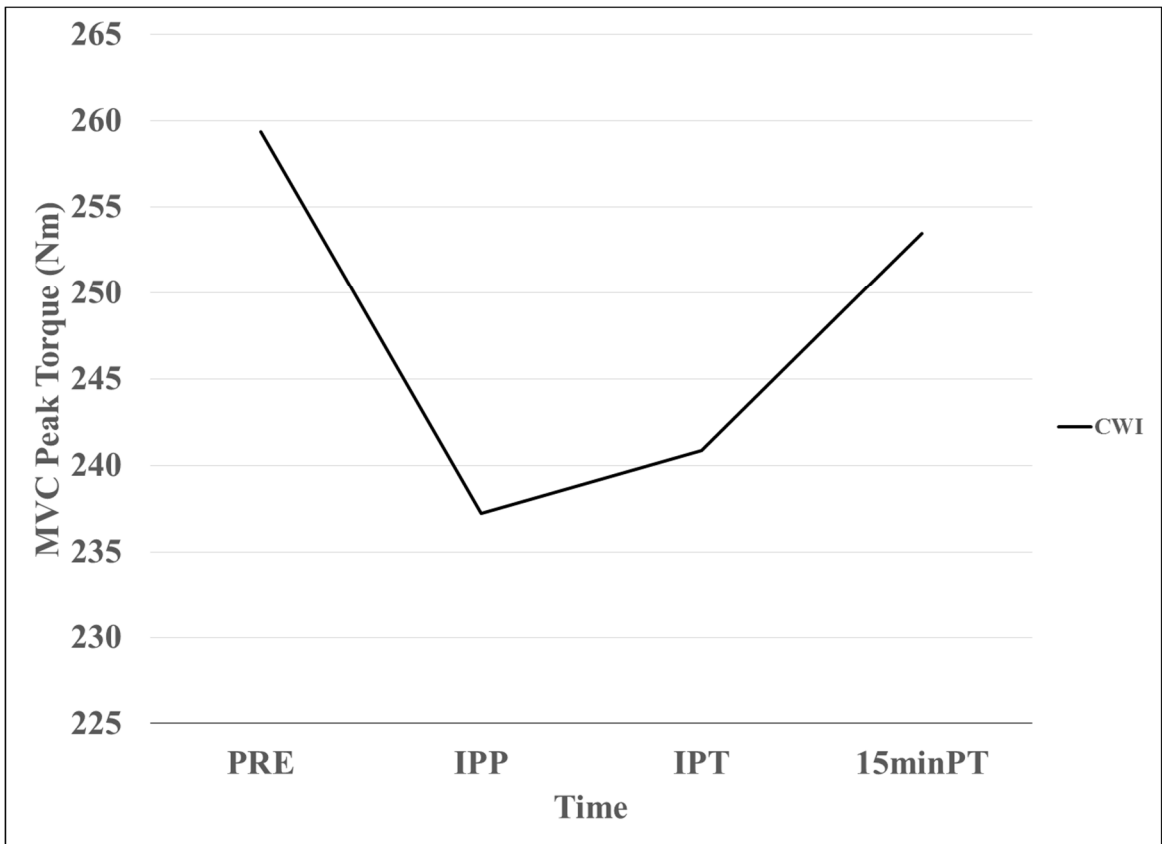


Figure 3. Exercised Leg MVC Peak torque values during control and treatment at time points, *PRE* Pre-exercise protocol, *IPP* Immediate post-

protocol, *IPT* Immediate Post-treatment or control. *indicates significant difference from *PRE*

Group mean MVC's for exercise leg for 4 time points during treatment condition are shown below in Figure 4. A significant difference over time within *PRE*, *IPP*, *IPT*, and *15minPT* was discovered when repeated measures testing was conducted for the exercised leg treatment visit [$F(3,33)= 3.358, p=0.030, N=12$]. No significant effect for time was found for exercised leg MVC torque during the control visit [$F(2,26)=1.799, p=0.185$]. During control there was no significant effect over time on MVC torque of the exercised leg [$F(2,26)=1.799, p=0.185, N=12$].

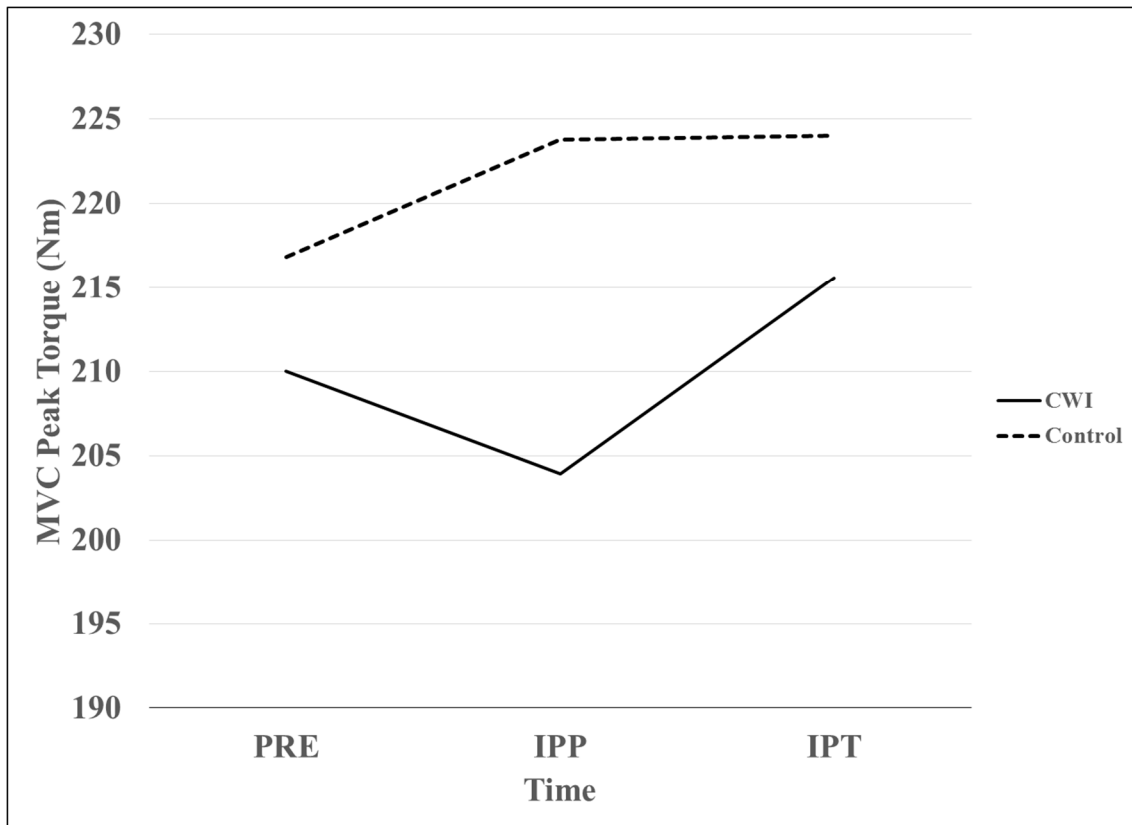
Figure 4. Exercised Leg MVC Peak Torque values during treatment visit only at 4 different time points, *PRE*, *IPP*, *IPT*, and *15minPT*



Group mean MVC's for the control leg (left leg) for each time point and both conditions are shown below in Figure 5. No significant visit x time interaction was found for control leg MVC torque [$F(2,26)=1.086, p=0.352, N=14$]. No significant main effect for time was found for

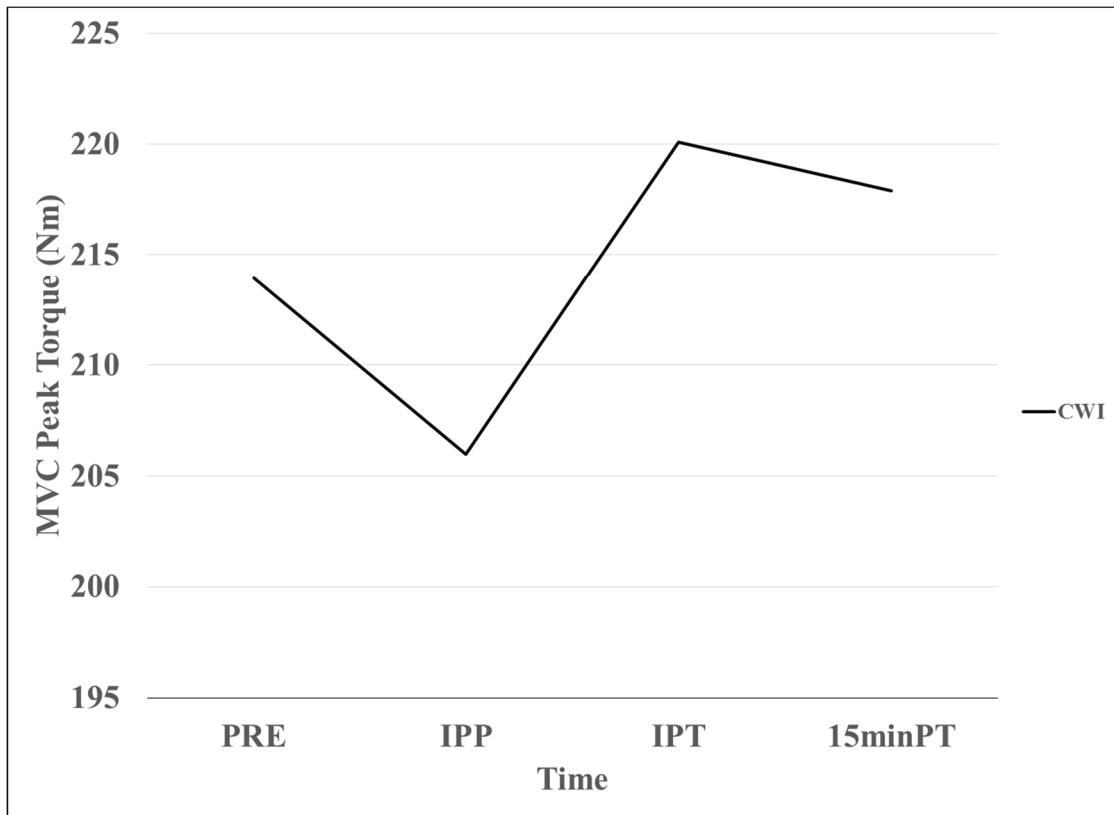
control leg MVC torque during treatment or control [$F(2,26)=0.871, p=0.430$]. A significant main effect for condition was discovered for the control leg MVC torque [$F(1,13)= 6.401, p=0.025$]. The control visit had significantly greater MVC than treatment visit regardless of time point.

Figure 5. Control Leg MVC Peak torque values during control and treatment visits at 3 different time points, *PRE, IPP, IPT*



Group mean MVC's for the control leg at 4 time points during treatment condition are shown below in Figure 6. No significant effect was found for time during left leg treatment visit [$F(3,33)=0.808, p=0.498, N=12$].

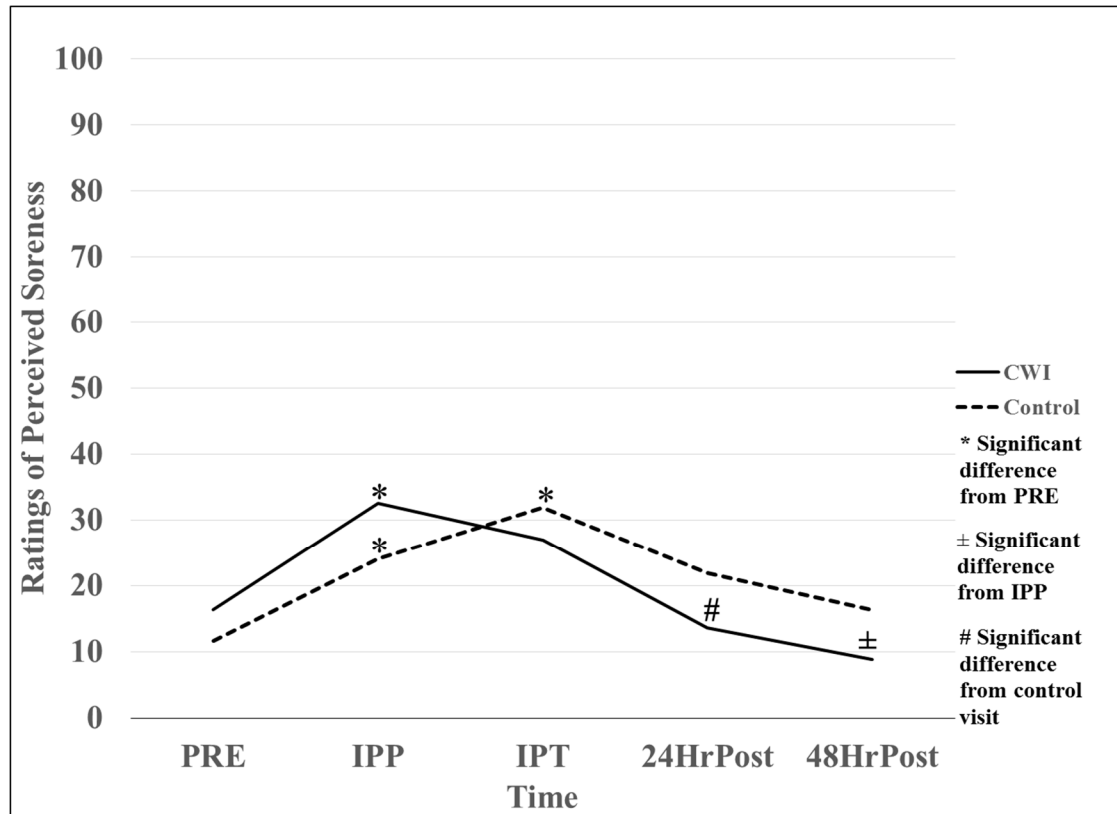
Figure 6. Control Leg MVC Peak Torque values during treatment visit only at 4 different time points, *PRE*, *IPP*, *IPT*, and *15minPT*



Perceived Soreness

Group mean perceived soreness scores for the exercised leg both conditions at 5 time points are shown below in Figure 7. A significant interaction between time and condition was found for perceived soreness of the exercised leg [$F(4,52)=5.207, p=0.001$]. A significant effect for time was revealed during a repeated measures ANOVA for the exercised leg perceived soreness during control visit [$F(4,52)= 5.546, p=0.001$]. Bonferroni pairwise comparisons showed that the *PRE* values for perceived soreness of the exercised leg during control were significantly different from time points *IPP* and *IPT* [$p=0.020, p=0.001$].

Figure 7. Perceived soreness of the exercised leg during both treatment and control at the time points *PRE*, *IPP*, *IPT*, *24HrPost*, *48HrPost*. * indicates significant difference from *PRE*, # indicates significant difference from control visit, ± indicates significant difference from *IPP*

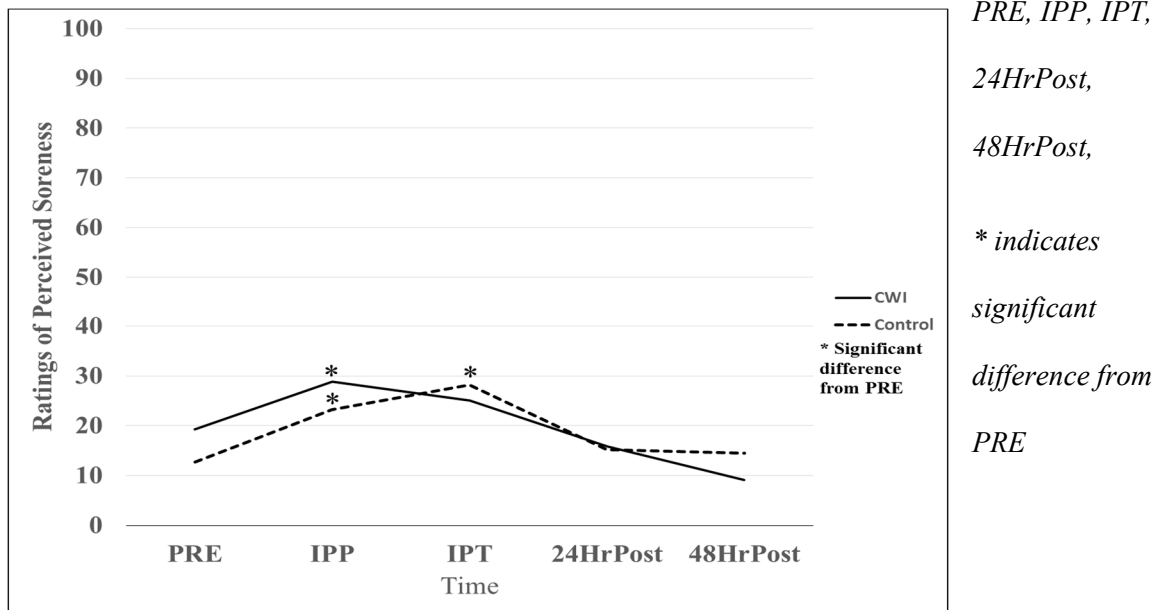


A significant effect for time was discovered during a repeated measures one way ANOVA of the exercised leg during treatment visit [$F(4,52)= 8.333, p < 0.001$]. A significant difference in perceived soreness from *PRE* values was discovered for *IPP* during treatment visit of the exercised leg [$p= 0.001$]. A significant difference in perceived soreness from *IPP* values was discovered for *48HrPost* during treatment visit [$p=0.033$]. A significant difference was found between control and treatment time point *24HrPost* for perceived soreness using a paired samples t-test [$p= 0.028$].

Group mean perceived soreness scores for control leg during both conditions at 5 time points are shown below in Figure 8. No significant visit x time interaction was discovered for

ratings of perceived soreness of the control leg during treatment or control [$F(4,52)=2.131$, $p=0.090$]. A significant main effect for time was discovered for ratings of perceived soreness of the control leg ($F(4,52)=4.992$, $p=0.002$). A significant difference from control *PRE* values was discovered for time points *IPP* and *IPT* when Bonferroni correction was used [$p=0.001$, $p=0.003$]. A significant main effect for time was discovered for ratings of perceived soreness of the control leg during treatment visit [$F(4,52)=4.101$, $p=0.006$]. A significant difference from *PRE* perceived soreness values was discovered for *IPP* during control leg treatment visit using a Bonferroni correction. [$p=0.010$]. Significant main effect for time was discovered for control leg perceived soreness during control visit [$F(4,52)=4.445$, $p=0.004$]. During control visit of the control leg a significant difference was found during time points *IPP* and *IPT* from *PRE* perceived soreness values [$p=0.005$, $p=0.000$]. No differences were found between control leg perceived soreness treatment and control time points when compared with one another using paired samples t-test.

Figure 8. Perceived soreness of the control leg during treatment and control at the time points



CHAPTER IV

DISCUSSION

Introduction

The hypotheses for this research thesis involved 3 different approaches. First, soreness scores were expected to be higher immediately after the control than the cold water immersion (CWI) treatment. Second, it was hypothesized that MVC torque would be higher after CWI than control for both the exercised and control leg. Lastly, it was hypothesized that CWI would reduce perceived soreness to a greater extent after the CWI treatment than control at the 24 and 48-hour post treatment time points. The primary research question examined whether or not CWI would improve recovery from a damaging bout of exercise. The secondary research question analyzed if CWI reduced perceived soreness following a damaging bout of exercise.

Primary Hypothesis

Paired samples t-tests found no significant difference between treatment *IPT* soreness and control *IPT* soreness [$p=0.386$]. Soreness scores were expected to be higher immediately after the control than the CWI treatment because of the hypothesized effect CWI would have on the perception of pain and soreness for each subject. This idea is well documented in the literature, specifically by Delextrat in a study involving basketball players, in which soreness was lower post CWI treatment in the treatment group compared to control group (Delextrat, González Hippocrate, & Clarke, 2013). Ingram found that soreness scores for the CWI group were lower post exercise than scores for control (Ingram, Dawson, Goodman, Wallman & Beilby, 2009). Ascensao discovered that perceived soreness was less in the CWI treatment group compared to

control subjects (Ascensao et al., 2011). These findings guided the first hypothesis of this research thesis. The findings from this study indicated that within the sample, perceived soreness for the exercised leg was not higher for *IPT* during the control visit than the *IPT* treatment (CWI) (see Figure 7.). During the control visit it was also found that soreness at the *IPT* time point was significantly different from control *PRE* values, while at the same time *IPT* of the treatment visit was not found to be statistically significant from treatment *PRE*. A significant difference, however, was found between treatment *24HrPost* and control *24HrPost* (see Figure 7.) [$p=0.028$].

The initial findings from the soreness scores for the exercised leg in this study, using an alpha level of 0.05, seem promising in supporting the efficacy of CWI reducing perceived soreness following treatment compared to control. Soreness was higher in the exercised leg after control than it was after the CWI treatment, specifically at the *24HrPost* time point, which a paired samples t-test found soreness to be significantly greater in control than treatment at *24HrPost* (see Figure 7.) [$p=0.028$]. During control visit for the exercised leg, soreness was higher immediately after finishing the exercise protocol (*IPP*) and control protocol (*IPT*) than it was at the pre-exercise time (*PRE*) [$p=0.020$, $p=0.001$]. This difference was found to be significant enough statistically and furthermore, the same time point during the exercise leg CWI visit (*IPT*), had scores that were not significantly different from CWI visit *PRE* [$p=0.163$]. CWI alleviated soreness for the exercise leg to the point that no increase from *PRE* values were recorded for treatment visit after time point *IPP*. Conversely, control did not alleviate soreness scores which could be responsible for statistically higher *IPT* soreness values for control. The final investigation for exercise leg soreness scores lies with the paired samples t-tests which compared the mean soreness scores at every time point for both conditions against each other for all subjects. The paired samples t-tests found a significant difference in soreness scores between conditions at time point *24HrPost* (see Figure 7.) [$p=0.028$]. CWI soreness was significantly

lower at *24HrPost* time point when compared to the same control time point. Although findings from this examination of the data support CWI treatment reducing soreness to a greater degree 24 hours post treatment than control, the primary hypothesis stated that soreness would be higher immediately after control than treatment, which time point *IPT* soreness was not found to be significantly higher for control than treatment. Therefore, the findings do not support the hypothesis that soreness scores were to be higher immediately post control than immediate post CWI treatment.

Control leg control visit had significantly higher *IPP* and *IPT* soreness than *PRE* control, revealing a similarity in the exercise leg and control leg soreness scores during control condition. During control leg treatment visit, *IPP* soreness was significantly higher than treatment *PRE*, also revealing a similarity between exercise leg and control leg soreness scores during treatment condition. The similarities end there however, due to the paired samples t-test revealing no differences to a significant level between conditions at any of the time points.

To answer the first research hypothesis, was *IPT* soreness higher for the control visit than the CWI treatment visit? Differences between exercise leg control *IPT* and treatment *IPT* were revealed to be insignificant in terms of statistical analysis (see Figure 7.). Similarly, the control leg had no significant differences between control *IPT* soreness and treatment *IPT* (see Figure 8.). These findings do not support the first hypothesis that *IPT* soreness would be higher for control visit than CWI visit.

Secondary Hypothesis

The second hypothesis of this research thesis was that MVC torque levels would be significantly higher after CWI than control for both the exercise and control leg. A similar hypothesis was examined briefly within the literature by Ingram in a 2009 study that found CWI participants had less decline in isometric strength than control group counterparts (Ingram et al.,

2009). Exercise leg MVC torque during *IPT* CWI was found to be lower than control *IPT*, but not to a significant level. The MVC torque at *IPT* CWI visit was found to be significantly lower than *PRE* CWI MVC torque. This indicated a decline in MVC torque of the exercise leg during the CWI visit with a slight increase in *IPT* from *IPP*, while there was a less noticeable decline in exercise leg MVC torque for control visit, with an increase in *IPT* from *PRE* (see Figure 3.) For the control leg it was discovered that *IPT* MVC torque during control was higher than MVC torque *IPT* during CWI treatment visit (see Figure 5.). This finding reveals a striking similarity between the exercise leg and control leg MVC torque at this time point during the study. Unlike the exercise leg, however, control leg MVC torque at *IPT* was higher than *PRE* MVC torque during the CWI visit although not to a statistically significant degree. This study added the contralateral leg (left leg) to its methods in order to evaluate the effect of CWI only on the contralateral limb. The left leg findings revealed that CWI did not have an effect on control leg (left leg) MVC torque.

Although not involved in hypotheses for this research thesis, another facet of the MVC torque merits attention. During CWI treatment visit a 4th time point, *15minPT* was added to further examine MVC torque levels of both exercise and control leg during the research process. This time point was added to allow each subject's knee extensors of both legs to return back to resting room temperature after CWI treatment in order to get a more unbiased reading of MVC torque for both legs. Since 10°C water causes considerable muscle cooling, *15minPT* time point was added in order to allow this consideration that *IPP* time point did not. This extra time point was only added during treatment visits and not control. Right leg MVC torque during treatment visit with an added time point (*15minPT*), had no significant differences in MVC torque during any of the time points (see Figure 4.). Control leg MVC torque during treatment visit with the added time point *15minPT*, also had no significant differences in MVC torque during any of the time points, although torque was higher at *IPT*, and *15minPT* than *PRE* (see Figure 6.). These

findings indicate that allowing the muscle to return to room temperature did not have any statistically significant effect on MVC torque of either treatment or control leg.

Tertiary Hypothesis

The last hypothesis of this research thesis was that soreness would be less during the treatment visit at *24HrPost* and *48HrPost* than the control visits for both exercise and control legs at those same time points. Soreness scores for the exercise leg treatment visit were significantly less than those for control at *24HrPost* (see Figure 7.) [$p=0.028$]. For the control leg it was revealed that soreness was not significantly different between CWI and control at *24HrPost* or *48HrPost* (see Figure 8.) [$p=0.873$, $p=0.215$]. The findings from this research indicate support for this hypothesis, albeit for the exercise leg, 24 hours post treatment only, and not for the control leg (left leg) at all.

Primary Research Question

The primary research question involved examining whether or not CWI would improve recovery from a damaging bout of exercise. In this discussion, I have evaluated the MVC torque of both legs at every time point for both conditions. I have also evaluated statistical analyses of each condition separately to better clarify the findings. Perceived soreness has also been closely examined for both legs at every time point for both conditions. Separate statistical analyses have been conducted on each leg and condition separately to also paint a better picture of the results in order to answer the research questions. Improving recovery from exercise involves restoration of MVC torque for both legs at time point post-CWI treatment compared to control (*IPT*). It also involves reduced soreness for both legs during CWI visit compared to control at every time point post CWI treatment (*IPT*, *24HrPost*, *48HrPost*). The results of this study have indicated that CWI did not improve MVC torque for both legs at every time point post exercise. MVC torque after control was higher than MVC torque after treatment for both exercise and control leg. When

comparing conditions using only the primary 3 time points (*PRE*, *IPP*, *IPT*) MVC torque was never higher for CWI than control at any time point. The data indicates for the primary research question, CWI did not improve recovery (as defined previously in the paragraph) from a damaging bout of exercise.

Perceived soreness was reduced for the exercise leg treatment visit to a significant level compared to exercise leg control at the time point *24HrPost* (see Figure 7.). These findings seem to support the hypothesis that CWI would reduce perceived soreness to a greater extent after the CWI treatment than control at the 24-hour post treatment time point. However, in order to validate the second component of the primary research question, perceived soreness would have to be higher for control than CWI at every time point after treatment (*IPT*, *24HrPost*, *48HrPost*). While it was statistically significantly higher at *24HrPost* as previously mentioned, it was not statistically different at *48HrPost* or *IPT* between conditions. The control leg would also have to have significantly higher soreness at *IPT*, *24HrPost*, and *48HrPost* for control than treatment in order to confirm the primary research question. The control leg had no significant difference in soreness between control and treatment condition at any time point (see Figure 8.). Therefore, the second component of the primary research question indicates that although certain benefits were derived from CWI, it ultimately did not improve recovery from a damaging bout of exercise to a statistically significant enough degree to support the primary research question.

Secondary Research Question

The secondary research question evaluated whether or not CWI reduced perceived soreness following a damaging bout of exercise. In order to answer this question, evaluation of the data involving perceived soreness of both exercise and control leg is necessary. As previously mentioned, it was established that CWI did not cause a significant difference in soreness between control and treatment at any time point for the control leg. These findings however, are not consistent with findings for the exercise leg. CWI did have a significant effect in reducing

soreness for treatment visit at *24HrPost*. Although the control leg in this study revealed no positive benefits of CWI regarding soreness, the exercise leg did display a significant reduction in soreness 24 hours after treatment compared to control. This leads the investigator to declare that CWI did reduce perceived soreness following a damaging bout of exercise 24 hours post treatment in the exercise leg. Although no such findings were found for the control leg (left leg), and significant reduction in soreness was only found at *24HrPost*, the data supports the secondary research question that CWI does reduce perceived soreness following damaging bout of exercise, in this case the exercise leg at *24HrPost*.

Practical Applications

The lack of evidence supporting the efficacy of CWI to restore MVC torque production of the knee extensors compared to control is why the secondary hypothesis and primary research question were not declared to support CWI. These findings indicate for this subject sample, CWI was not an effective recovery modality for restoring MVC torque compared to control. The results from the perceived soreness scores however, showed support for CWI reducing perceived soreness to a significant level 24 hours after CWI compared to control. For strength and conditioning professionals, these findings indicate that CWI conducted after training, practice, or competition has legitimacy as a perceived soreness recovery modality. Alleviating perceived soreness in a similar subject sample, up to 24 hours after a CWI treatment, conducted in a similar fashion as the one in this thesis, could have positive benefits for recovery from symptoms of delayed onset muscle soreness (DOMS).

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APPENDICES

Appendix A. Assumptions

For the purposes of this study it is assumed that: 1) subjects will complete the exercise protocol and MVC testing to their maximum capabilities; 2) athletes will refrain from altering their diet, lifestyle or other daily activities that might affect study results; 3) athletes will refrain from any lower extremity exercise for the duration of their individual testing time span.

Appendix B. Limitations of the Study

The subjects of this study are active males with a history of resistance training and, therefore, are likely to have a desire to continue training during the study duration. The researcher has no control over what subjects do outside of the research laboratory other than stating the requirements of participation. Subjects are also between the ages of 18-26 so extrapolating any findings from this study to populations other than males between the ages of 18-26 with a history of resistance training would be inappropriate. The CWI protocol consists of immersion in 10°C water for 5 consecutive minutes, therefore, findings from this study can only confidently be made regarding the same CWI treatment protocol.

Appendix C. Significance of the Study

This study examines males with a history of resistance training instead of sedentary individuals. In addition, this study examines males between the ages of 18-26 instead of an elderly sample. This study is also the first study to examine the contralateral leg effects of CWI on MVC and perceived soreness.

Appendix D. Definition of Terms

To achieve clarity a list of operationally defined terms listed below:

- Perceived soreness – As defined in this study as feelings of muscle soreness as described by the study subject
- Perceived fatigue – As defined in this study as feelings of muscular fatigue as described by the study participant
- Muscle Damage- symptoms including “impaired muscle function, pain, swelling, decreased ability to generate tension and loss of motion” brought on by exercise (Kraemer et al., 2001, p. 282)
- Blood markers – As defined in this study as blood markers related to muscular soreness including myoglobin, and C-reactive protein
- Myoglobin - blood protein that has oxygen molecules bonded it to it; when exercise occurs myoglobin provides extra oxygen to the working muscle and when muscle damage occurs myoglobin is released into the bloodstream in excess (Bailey, Erith, Griffin, Dowson, Brewer, Gant & Williams, 2007)
- C-reactive protein (CRP) - a protein found in blood that plays a role in inflammation and can be found in the body in places where inflammation is likely or has already occurred (DuClos & Mold, 2004)

Appendix E. Review of Literature

REVIEW OF THE LITERATURE

The purpose of this review was to examine the current literature regarding the use of CWI for recovery from perceived soreness, muscle damage and muscular fatigue after exercise. Within the scope of this review, highlights will be made regarding perceived soreness and how it relates to CWI treatment, exercise performance and how it is affected by CWI. The first section of this literature review will involve an examination of muscle damage, muscular swelling and the physiological process involved at the cellular level within the muscle, and how CWI treatment affects this process. The second section of this literature review will involve an examination of perceived soreness and the findings that have been discovered regarding CWI treatment. After this section, a review of literature involving exercise performance and how it is affected by CWI treatment will be highlighted.

Muscle Damage

Muscle damage can occur when strenuous exercise, practice or sport competition is participated in. Muscle damage is commonly quantified by measuring isometric maximal voluntary contraction or MVC (Warren, Lowe, & Armstrong, 1999). By measuring this isometric strength level it provides researchers with a valid method for quantifying muscle ability and function before, during, or after exercise (Byrne & Eston, 2002). This is a desirable quantification because athletes that can execute athletic movements forcefully when fatigued stand a better chance of success during competition. This is especially true for eccentric muscle strength which has been regarded particularly susceptible to muscle damage (Byrne & Eston, 2002).

Byrne & Eston, 2002

Byrne and Eston conducted a muscle damage study involving 8 participants with active lifestyles but not currently resistance training their lower limbs. Isometric strength measures and dynamic knee extensor strength was measured using a dynamometer before the exercise protocol began to establish a baseline (Byrne & Eston, 2002). Vertical jump was measured pre-study using an electronic timing mat as well as squat jump, countermovement jump and drop jump (Byrne & Eston, 2002). Creatine kinase was the last criterion measured to establish baseline before the exercise protocol began (Byrne & Eston, 2002). These measurements were also taken 1 hour after the exercise protocol, 1,2,3,4, and 7 days after the exercise protocol as well (Byrne & Eston, 2002). The exercise protocol designed to induce muscle damage involved 10 sets of 10 repetition barbell squats loaded with 70% of each participant's body mass for intensity (Byrne & Eston, 2002). The researchers found that there was no significant difference in isometric, concentric or eccentric strength reductions after the muscle damaging exercise protocol (Byrne & Eston, 2002). Strength was reduced by 20% 1 hour after exercise, 25% 1 day later, 21% 2 days later, 15% 3 days later and 13% lower 4 days after exercise (Byrne & Eston, 2002). Vertical jump measurements taken post exercise were reduced for 3 days compared to baseline (Byrne & Eston, 2002). The data revealed that countermovement jump performance diminished to a greater extent than squat jump and drop jump measures which were also reduced compared to baseline (Byrne & Eston, 2002). It was apparent that muscle damage occurred following the exercise protocol due to the reduction in strength measurements for 4 days after the protocol as well as the reductions in jump performance for 3 days post exercise (Byrne & Eston, 2002). Creatine kinase was elevated in the subject's 1 hour after exercise and reached max levels 1 day after exercise before plateauing back to baseline 4 days post exercise (Byrne & Eston, 2002).

Robey, Dawson, Goodman, & Beilby, 2009

The sport of rowing involves considerable physical demands upon the athletes that participate in it competitively or even for leisure (Robey, Dawson, Goodman & Beilby, 2009). It is because of these demands upon the body that researchers at the University of Western Australia examined the effect of various recovery procedures on leg strength, row performance indicators and muscle damage during a 72 hour post exercise window after a stair-climb running protocol (Robey, et al., 2009). The study sample involved 20 amateur rowers in the Amateur Rowing Association of Western Australia. Baseline measures of peak torque using a dynamometer (dominant leg max concentric extension), 2km row ergometer test, and serum creatine kinase levels were measured for comparison criterion (Robey, et al., 2009). After baseline measures were established the subjects participated in three experimental trials of the stair-climbing run over an 8 week period, with each individual trial lasting a week in duration and involving 5 sessions of baseline performance (max concentric leg extension), training run, recovery workout, and baseline performance again (Robey, et al., 2009). The 3.6km run course included a set of 242 stairs in the middle of the “out and back” course (Robey, et al., 2009, p.250). Based upon their running fitness, participants were “assigned a set number (3,5,7, or 9) or a full stair-climb repetitions to complete” (Robey, et al., 2009, p.250). The researchers encouraged the subjects to complete the run as fast as they could and to perform the stair climb section of the run with as much energy and speed as they could muster. After each run the participants were tested in the lab for indicators of muscle damage and then performed a randomly assigned recovery procedure (control, stretching modality, or hot/cold immersion alternating therapy). Those randomly assigned to the control group simply remained seated in a room for 15 minutes (Robey, et al., 2009). The subjects randomly assigned to the stretching recovery protocol underwent 15 minutes of static stretching involving 8 assorted lower body muscle stretches held for approximately 30 seconds then repeated two more times (Robey, et al., 2009). Those subjects who were assigned to the hot/cold treatment alternated between a hot shower at 40°C for 2 minutes then an ice bath up

to the anterior iliac spine in 12°C water for 1 minute, with the whole protocol repeated five times (Robey, et al., 2009). The results of this study revealed that there was no significant impact on leg extension peak torque in any of the recovery treatments (control, stretching, or alternating CWI/Hot water) compared to baseline measures (Robey, et al., 2009). There were also no significant differences in 2km row ergometer times between any of the recovery protocols compared to baseline measures (Robey, et al., 2009). None of the recoveries had a significant effect on CK levels post-run compared to baseline measures of CK (Robey, et al., 2009). Robey and company ultimately found no significant differences between the 3 different recovery strategies on any criterion measured at any point during the study (2009). It was determined that hot/cold water alternating therapy and the static stretching protocol had no effect on recovery from the stair-climb running protocol compared to control (Robey, et al., 2009).

Skurvydas et al., 2006

A study conducted in Lithuania attempted to examine the effect of leg immersion in cold water on indicators of muscle damage after exercise designed to induce muscle damage via the stretch shortening cycle (Skurvydas et al., 2006). The 20 male subjects involved in this study were self-described as being physically active but did not participate in exercise or sport. Baseline measures were established before the experimental trial began and included: max muscle voluntary contraction (MVC) using a dynamometer, force of quadriceps muscle using electrical stimulation, maximal drop jump height, perceived muscle soreness at 24 hours after exercise, 48 hours, and 72 hours, and creatine kinase levels before exercise, 24 hours after exercise, and 48 hours after exercise (Skurvydas et al., 2006). The researchers utilized a crossover type study design with the subjects performing the exercise protocol then followed by a random assignment to either the control recovery (no CWI) or the experimental group (CWI). After the subjects performed the first experimental trial several months were allowed to elapse before they conducted the other recovery method that they had not performed yet (Skurvydas et al., 2006). In this manner each subject participated in both the control and experimental group. The exercise

protocol utilized in the study to induce muscle damage involved a session of 100 drop jumps of maximal effort from a 0.75m platform mounted with a Kistler force plate with a single jump being performed every 20 seconds (Skurvydas et al., 2006). After the 100 drop jumps were performed the subjects were immediately retested for MVC and force of quadriceps muscle using electrical stimulation (Skurvydas et al., 2006). Immediately following retesting of force variables the subjects were immersed in 15°C water for 15 minutes followed by a 10 minute break from CWI, which was then followed by a 2nd 15 minute session in the 15°C water following exercise (Skurvydas et al., 2006). This CWI protocol was completed in entirety again at 4 hours post exercise, 8 hours post exercise and finally at 24 hours post exercise (Skurvydas et al., 2006). Results from data collection indicated that CWI after the exercise protocol “accelerated the disappearance of indirect indicators of muscle damage” (Skurvydas et al., 2006, p. 146). This was concluded due to the fact of that CK levels were reduced following CWI treatment in the experimental group and reduced muscle soreness in the experimental group. No differences were found between the control group and experimental group in regards to maximal voluntary contraction, quadriceps force utilizing electrical stimulation or maximal drop jump heights. It was concluded in this study that CWI after the exercise protocol hastened the departure of indicators related to muscle damage including CK and perceived muscle soreness compared to the control group treatment (Skurvydas et al., 2006).

Eston & Peters, 1999

Previously in this literature review the majority of studies examined have involved CWI treatment and exercise protocols targeted at lower body musculature and the effect CWI treatment has on these large muscle mass areas. Contrary to this trend, the next article reviewed focused on elbow flexors brought to muscle damage and how CWI post exercise affected these flexors. Eston & Peters sought to examine the effects of CWI post exercise on symptoms of muscle damage in elbow flexor muscles of 15 females (Eston & Peters, 1999). Their study involved 15 females from the University of Wales between the ages of 20-24 (Eston & Peters, 1999). Baseline

measures were recorded before the exercise protocol or treatment was conducted and included: baseline CK levels (fingertip blood sample), isometric strength of elbow flexors (dynamometer), relaxed arm angle (goniometer), local muscle tenderness (algometer), and upper arm circumference using anthropometric tape measurement. (Eston & Peters, 1999). These measurements were determined before exercise began as well as retested every 24 hours after exercise for a period of 3 days (Eston & Peters, 1999). The exercise protocol in this study consisted of 8 sets of 5 maximal contractions both eccentrically and concentrically with 60 seconds of rest performed between each set on the dynamometer (Eston & Peters, 1999). Following the exercise bout, the participants conducted their randomly allocated treatment group (control or CWI). The CWI treatment involved the subjects submerging their exercised arm into 15°C water up to the origins/insertions of the biceps for 15 minutes (Eston & Peters, 1999). The researchers found no evidence from their data indicating CWI treatment post exercise had any positive benefit on muscle tenderness, swelling or max isometric strength (Eston & Peters, 1999). It was discovered that by days 2 and 3 post exercise, CK levels were higher for the control group compared to the treatment group (Eston & Peters, 1999). Eston & Peters proposed that this could be because of a “reduction in the amount of post-exercise damage as a result of cold application in the treatment group” (1999, p. 236). As far as relaxed arm angle, the treatment group was found to have less of a decrease in the relaxed arm angle measurement compared to the control, which attributed an increased range of motion in the treatment group subjects (Eston & Peters, 1999). This study revealed no evidence regarding efficacy for CWI as a treatment modality for muscle tenderness, swelling or markers of isometric strength (Eston & Peters, 1999).

Santos et al., 2012

Sports that involve combatant type activity place high risk on participants. Athletes within these sports would stand to benefit greatly from any recovery modalities that would potentially assist them, including CWI (Santos et al., 2012). Researchers in Brazil conducted a study involving 9 highly trained male jiu-jitsu athletes (Santos et al., 2012). Their study focused

on CWI post exercise and the effect treatment had on creatine phosphokinase (CPK), lactate dehydrogenase (LDH), grip strength, and perceived pain in their study subjects (Santos et al., 2012). Baseline criterion was collected before the experimental protocol began and included: CPK levels (blood sample), LDH levels (blood sample), grip strength (Judogi Handgrip Test), and perceived pain determined by a visual analog scale (Santos et al., 2012). After baselines measures were determined the 9 participants began the exercise protocol that involved two 90 minute training sessions. These sessions involved: 30 minutes general exercise or gymnastics, 30 minutes of technical training (guard passes, sweeps, arm-locks, submissions, etc.), and lastly, 30 minutes of fighting (5 matches with 1 minute rest between matches). After the training session the randomly selected treatment group immersed themselves in a 5°C pool for 19 minutes as their CWI protocol (Santos et al., 2012). During this time the control group simply sat in a room temperature room for the duration of the CWI treatment. During the second session, which was conducted two days later, a cross-over study design was utilized. After the same exact exercise protocol the participants switched their post-exercise treatment groups (Santos et al., 2012). Post-exercise tests of criterion measures included CPK levels, LDH levels, grip strength, and perceived pain (Santos et al., 2012). Results of the study indicated that CPK levels only significantly increased for the control condition during both sessions (Santos et al., 2012). Statistically significant increases in LDH were found in both treatment groups when compared to baseline, but post-exercise values were much higher in the control group compared to the CWI group (Santos et al., 2012). Interestingly, decreases in grip strength were found only in the control condition when compared to baseline and between treatment groups (Santos et al., 2012). A statistically significant increase in perceived pain scores was observed between the baseline and post-exercise time markers, with the CWI group displaying hypoalgesia effects, which is a decreased sensitivity to pain (Santos et al., 2012). Results of this study displayed that CWI post-exercise reduced CPK, LDH, perceived pain and maintained grip strength in the treatment group compared to control (Santos et al., 2012).

Junior et al., 2014

In a study very similar to the previously mentioned research by Santos et al., Junior and other researchers examined the acute effects of CWI on CPK, LDH, perceived pain, and grip strength in high level jiu-jitsu athletes (Junior et al., 2014). The study involved 10 highly trained male jiu-jitsu athletes who participated in simulated jiu-jitsu match competitions to induce muscle damage and fatigue (Junior et al., 2014). Before the exercise commenced, the fighters were measured for baseline criterion variables including CPK (blood sample), LDH (blood sample), grip strength (kimono grip endurance test), and perceived pain determined by a visual analog scale (Junior et al., 2014). After the variables were established the exercise protocol commenced, which involved 2 sessions of simulated combat with the second session commencing 2 days after the first session ended (Junior et al., 2014). Each session comprised of four 7 minute fights with a 15 minute rest interval between each fight (Junior et al., 2014). Participants were paired based on similar skill level and ability in order to ensure maximum effort during each fight (Junior et al., 2014). After the final fight in a session, perceived pain was recorded and then the post-exercise treatments began with CWI consisting of immersion in 5°C water for 19 minutes, and the control group simply sitting in a room quietly (Junior et al., 2014). It was discovered that the CWI group had lower levels of LDH compared to the control (Junior et al., 2014). CWI treatment also resulted in lower CPK concentrations as well as lower perceived pain scores compared to subjects within the control group (Junior et al., 2014). Interestingly, unlike the previously mentioned study, grip strength performance within this study did not differ between the CWI and control group (Junior et al., 2014).

Goodall & Howatson, 2008

Drop jumps were utilized by Goodall & Howatson for an exhaustive exercise protocol aimed at examining the effects of CWI post-exercise on MVC, CK, perceived soreness, and range of motion (ROM) in 18 male athletes between the ages of 19-29 (2008). These variables were measured pre-exercise, 24 hours post-exercise, 48 hours, 72 hours, and 96 hours post-exercise

(Goodall & Howatson, 2008). The exercise protocol involved 100 drop jumps broken down into 5 sets of 20 jumps (Goodall & Howatson, 2008). Subjects dropped from a 0.6m high box, then upon landing immediately jumped forcefully as high as possible before landing on the same surface again (Goodall & Howatson, 2008). Between each individual jump within a set 10 seconds of rest were allowed, and between each individual set 2 minutes of rest were allowed (Goodall & Howatson, 2008). Upon completion of the exercise, subjects were randomly assigned to either the CWI treatment group or the control. Those assigned to the CWI treatment group were submersed in 15°C water for 12 minutes on five separate occasions; immediately post-exercise, 24 hours post-exercise, 48 hours, 72 hours, and again at 96 hours post-exercise for the final immersion (Goodall & Howatson, 2008). The control group simply sat quietly in a chair during each of these treatment times. The researchers found no significant differences between groups in any of the variables measured and concluded that “CWI did not enhance recovery from a bout of damaging eccentric contractions” (Goodall & Howatson, 2008, p. 235).

This section of the literature review focused on the potential impact CWI could have on muscle damage in athletes from various sports tested in a variety of different ways. Muscle damage was determined by the studies in this section by using a variety of markers including: MVC, CK, perceived soreness, ROM, and LDH. Much of the information in this section provided research evidence that did not support the efficacy of CWI for treatment of muscle damage. For example Robey and company discovered no significant impact of CWI on leg extension peak torque, 2km row ergometer times or CK levels after CWI conducted post intense exercise (2009). Similarly Eston & Peters found no significant effect of CWI conducted after intense exercise of the elbow flexors, although increased ROM was noticed in the treatment group post treatment compared to control (1999). Goodall & Howatson discovered similar findings in their study involving drop jumps and CWI, causing the authors to conclude that CWI had no effect on recovery within their study design (2008). Contrary to those findings, Skurvydas and researchers found that CWI reduced CK levels in their CWI treatment group which also saw reduced muscle

soreness scores compared to control (2006). A similar trend was noticed in jiu-jitsu athletes that participated in CWI after intense exercise, which the researchers saw reduced perceived soreness scores compared to control (Santos et al., 2012). These same findings were present in another study involving combatant athletes which saw reduced LDH, CPK, and perceived soreness scores in the treatment group compared to control (Junior et al., 2014). Conflicting results were present in the studies included in this section of the review indicating a need better clarification of the most relevant markers to indicate muscle damage by researchers on the topic. Several studies showed that CWI had no relevant effect at all on any markers of muscle damage within their study (Robey et al., 2009; Eston & Peters, 1999; Goodall & Howatson, 2008). Three studies however, showed that CWI did have a statistically significant effect on markers within their research (Skurvydas et al., 2006; Santos et al., 2012; Junior et al., 2014).

CWI & Biomarkers of Muscle Swelling

Montgomery et al., 2008

Myoglobin is an important substance in the blood that provides extra oxygen to working muscle during times of muscle damage commonly brought on by exercise (Bailey et al., 2007). Montgomery and company sought to examine the relationship between intense competitive exercise, in this case a basketball tournament, cold water immersion, and the effect the recovery modality had on muscle damage markers, most notably myoglobin levels (Montgomery et al., 2008). In their study, 29 male basketball players were tasked with participating in a three day basketball tournament that involved a single game each day. After each game on all three days the players underwent a post-game recovery treatment of which they were randomly assigned. The recovery treatments were: carb replenishment and stretching (control group), cold water immersion at 11°C for a single bout of 5 minutes, or lastly the full leg compression treatment post game (Montgomery et al., 2008). Players only participated in the recovery modality they were specifically assigned after every game. Cold water immersion treatment group subjects were immersed in the 11°C water in a depth up to their sternum. Montgomery and researchers found

that the cold water immersion treatment had the most significant effect in reducing myoglobin levels compared to the control and compression treatment. The researchers hypothesized that cold water immersion had the most profound “acute analgesic effect” and recommend this form of recovery for athletes (Montgomery et al., 2008, p. 249).

Bailey et al., 2007

The next article reviewed in the literature observed 20 male subjects during a 90 minute intermittent shuttle run followed immediately by CWI to test markers of muscle damage, perceived soreness and changes in muscle function (Bailey et al., 2007). The subjects in the study were all young, healthy males who were self-reported to be physically active. The subjects performed isokinetic dynamometry test, vertical jump test and a perceived muscle soreness questionnaire before performing the shuttle test. Once the athletes performed the Loughborough Intermittent Shuttle Test they reported immediately to their randomly selected treatment group either the CWI group or control (Bailey et al., 2007). The cold water immersion group immersed themselves up to their iliac crest in 10°C water for 10 consecutive minutes. The control group simply sat in a quiet room while the treatment group sat in water. When the results of this study were analyzed it was found that the CWI group had less reduction in post exercise maximal isometric knee extension test than the control group. The vertical jump measures for both groups decreased post exercise and no significant differences were found between the groups. Myoglobin concentration was reduced one hour after exercise in the cold water immersion treatment group indicating a significant acute effect (Bailey et al., 2007). The CWI group in this study reported significantly lower ratings of perceived soreness after exercise than the control group (Bailey et al., 2007). Bailey & company concluded that a lone session of cold water immersion after exercise can reduce symptoms associated with intense muscle damaging exercise (Bailey et al., 2007).

C-reactive protein (CRP) is the last important biomarker of blood damage that will be discussed. CRP is a protein found in the blood that is associated with swelling and muscle damage (DuClos & Mold, 2004). CRP is commonly found in areas of the body that have swelling and is therefore considered a reliable biomarker of swelling following exercise (DuClos & Mold, 2004). When the body's inflammatory response is at its highest CRP levels become very elevated in order to compensate (DuClos & Mold, 2004). When CRP is found at these exaggerated levels it acts as an inflammation suppressor (DuClos & Mold, 2004). This is accomplished because reducing swelling, which catalyzes a host of potential problems for athletes including stiffness, loss of range of motion and pain, is potentially of benefit for athletes (Wilcock, Cronin, & Hing et al., 2006).

Brophy-Williams, Landers, & Wallman, 2011

A study conducted at the University of Western Australia sought to examine the effects of cold water immersion performed directly after or 3 hours post “high intensity interval exercise session” (HIIS) on next day exercise ability and performance (Brophy-Williams, Landers & Wallman, 2011). The study was comprised of 8 well trained male athletes with a history of exercise and sport participation. The study design involved all 8 athletes performing three HIIS at 90% of their VO₂ max velocity directly followed by the passive control recovery, CWI immediately post-exercise, or lastly, CWI performed 3 hours after exercise completion (Brophy-Williams, Landers & Wallman, 2011). After completion of recovery treatments the participants returned 24 hours later and completed a muscle soreness and total quality recovery perception questionnaire (TQRP) (Brophy-Williams, Landers & Wallman, 2011). After these were completed a final Yoyo Intermittent Recovery Test was conducted (YRT). Blood samples were collected before the exercise protocol and before the YRT to measure CRP levels (Brophy-Williams, Landers & Wallman, 2011). Both the CWI directly after exercise and the CWI treatment group conducted 3 hours after exercise were submerged up to the mid-sternum level in

15°C water for 15 minutes. It was discovered that immediate CWI after exercise resulted in improved YRT performance times compared to the control group. After a qualitative analysis the researchers also hypothesized that the CWI immediately after exercise was more beneficial than CWI 3 hours after exercise. The immediate CWI treatment group also saw the largest % change in CRP levels measured 24 hours after exercise was conducted (Brophy-Williams, Landers & Wallman, 2011).

Jajtner et al., 2015

A study done in 2015 also revealed findings involving CWI and CRP levels and the effect CRP had on inflammation in a study sample (Jajtner et al., 2015). Thirty male subjects who had experience with resistance training were selected for a study sample that sought to compare electrical stimulation treatment and cold water immersion and the effects the two treatments had on post-resistance exercise muscle soreness (Jajtner et al., 2015). On the first visit to the laboratory the study subjects established their 1 repetition maximum lifts in the deadlift, barbell split squat and barbell back squat. On the second visit the exercise protocol was conducted which involved the participants performing 4 sets of the squat, deadlift and split squat. The participants were encouraged to perform as many repetitions as possible within each set, but were told not to perform more than 10 repetitions. The squat exercise was conducted with each participant attempting to lift 80% of their previously determined 1RM (Jajtner et al., 2015). The deadlift and split squat exercises were loaded with 70% of the subject's previously measured 1RM (Jajtner et al., 2015). Two more sessions of this same exercise protocol were conducted 24 hours later and 48 hours after the initial regimen (Jajtner et al., 2015). Blood samples, measures of pain, soreness and recovery as well as an ultrasonography were conducted at 5 separate times during the study: pre-exercise for baseline, immediately after exercise, 30 minutes after exercise, 24 hours after exercise, and 48 hours post exercise. The participants were immersed in water regulated between 10-12°C immediately after exercise. Subjects were immersed in the water up to their umbilicus

for 10 minutes. The results of this study revealed that 30 minutes after exercise the CWI group had elevated levels of blood biomarkers related to muscle damage including CRP. This data suggests that ice water baths may “delay recovery within the first 30 minutes after exercise” (Jajtner et al., 2015, p.105). When CRP levels were taken again at 24 hours post exercise the data revealed that levels were increased from the 30 minutes post exercise level for both treatment groups and the control group (Jajtner et al., 2015). When blood samples were taken for the final time at the 48 hour post exercise time period CRP levels were diminished from the 24 hour period for both treatment groups and the control group but the most significant reduction was in the CWI treatment group (Jajtner et al., 2015). The authors concluded that the spike in CRP levels was most likely a result of the role of CRP in muscle repair (Jajtner et al., 2015). It was further hypothesized that these elevated CRP levels, especially seen in the CWI treatment group, potentially could have accelerated the body’s immune response and also aided in faster muscle remodeling (Jajtner et al., 2015).

Further research regarding CWI modalities, exercise performance and muscle damage has been conducted with an added emphasis on examining CRP levels in athletes. A study conducted at Queensland University in Australia focused on the effects of cooling strategies performed after exercise on recovery of various neuromuscular, cerebral, and physiological measures after sprint exercise in a heated environment (Minett et al., 2014). Cerebral oxygenation has gained considerable exposure recently due to the implications it possibly has on exercise performance (Minett et al., 2014). It has been proposed that heat stress brought on by exercise reduces cerebral oxygenation and cerebral blood flow which in turn reduces cardiac output and arterial pressure within the body (Gonzalez-Alonso et al., 2004). These reductions have been hypothesized to also affect motor control and motor unit output which also affects exercise performance (Amann & Kayser, 2009).

Minett et al., 2014

There were 9 male subjects involved in the study between the ages of 19-23, that were “moderate to well trained” with history of team sport activity (Minett et al., 2014). Baseline measures were recorded including: MVC (dynamometer), cerebral oxygenation using near-infrared spectroscopy (NIRS), perceived soreness, CK (blood sample), and CRP levels obtained from blood work as well (Minett et al., 2014). These variables were all measured before the exercise protocol, post-exercise protocol, post recovery treatment, 1 hour after exercise, and 24 hours after exercise (Minett et al., 2014). The exercise protocol consisted of 3 separate experimental trials that were each separated by a week (Minett et al., 2014). Each exercise trial consisted of 2x35 minute sessions of intermittent sprint exercise which included five sets of 15m sprints every 30 seconds (Minett et al., 2014). The sprint sets were separated by 5 minute periods of 15m shuttles of varying intensities and difficulty including hard run, jog, and walk (Minett et al., 2014). Each session totaled 10 sets of sprints and 8 periods of shuttle running conducted at a submaximal pace (Minett et al., 2014). Within 10 minutes of exercise protocol completion, the subjects began their randomly assigned recovery, either control, CWI, or mixed methods cooling for 20 minutes (Minett et al., 2014). The CWI group was submersed in 10°C water up to the mesosternal level for 20 minutes (Minett et al., 2014). The mixed methods recovery group had a cold towel positioned over the head, neck, and shoulders with an ice vest covering the torso, quadriceps and hamstrings (Minett et al., 2014). The towels for the mixed method group were soaked in 5°C water and the ice vest and ice pack were stored in -20°C before application (Minett et al., 2014). The control group simply sat in a quiet room for 20 minutes (Minett et al., 2014). Results of this study indicated that CWI restored MVC levels to pre-exercise ranks and CWI also resulted in higher mean MVC values post-recovery, 1 hour post-exercise, and 24 hours post-exercise compared to control (Minett et al., 2014). CWI also had greater MVC 1 hour post-exercise than mixed methods cooling group (Minett et al., 2014). Interestingly, cerebral blood

volume and oxygenation were decreased quite considerably in all recovery groups post-exercise compared to pre-exercise (Minett et al., 2014). It was also discovered that there were no significant differences between recovery treatment groups in regard to CK and CRP levels in pre-exercise and post-exercise data collection time points (Minett et al., 2014). Lastly, subjects in the CWI treatment group had reduced perceived soreness at every time point within the study compared to control and mixed methods cooling, while mixed methods cooling had reduced soreness compared with control at the 24 hour post-exercise mark (Minett et al., 2014).

This section of the literature provided more consistent findings amongst the studies included that focused on CWI and the effect treatment has on markers of muscle swelling. As previously mentioned, two of the key markers of muscle swelling include myoglobin and CRP. Montgomery et al., studied basketball players and subjected them to CWI after intense exercise, and found that CWI had a more significant effect in reducing myoglobin levels in the treatment group compared to the control group or alternate compression treatment group (2008). Similar to those results, Bailey and company found that myoglobin levels were reduced one hour after exercise and treatment in the CWI group compared to control (2007). Several studies within this section also analyzed CRP concentrations within their subjects during research in order to quantify muscle damage and recovery. In 2015 a study involving experienced, male, resistance trained athletes participating in intense exercise (squat, deadlift, split squat) had findings similar to those of Bailey et al., and Montgomery et al. (Jajtner et al., 2015). CRP levels were diminished at the 48 hour time mark compared to the 24 hour time mark for both treatment groups as well as control, but CWI treatment experienced the most significant reduction in CRP levels compared to all other groups (Jajtner et al., 2015). The last study in this section had dissimilar results as the majority of the other research. Minett et al., discovered no significant differences between the recovery treatment group and control in terms of CRP levels measured pre-exercise and post-

exercise (2014). This led researchers to conclude CWI had no significant effect on CRP levels, or reduction in muscular swelling when compared to control (Minett et al., 2014).

Perceived Soreness

Perhaps the biggest proponents of cold water immersion efficacy are the studies and articles that have documented CWI and its ability to minimize perceived soreness in subjects after exercise (Ascensao, Leite, Rebelo, Magalhaes, & Magalhaes, 2011; Duffield, Murphy, Kellett, & Reid, 2014; Parouty, Haddad, Quod, Lepretre, Ahmaidi, & Buchheit, 2010; Rowsell, Coutts, Reaburn, & Haas, 2009). Furthermore, several of these studies have found that CWI treatment helped reduce perceived soreness in athletes involved in exercise or sport related events designed to induce muscle fatigue and muscle soreness (Ascensao et al., 2011; Duffield et al., 2014; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Montgomery et al., 2008). This has brought great attention on CWI treatment as a modality for helping athletes in all sports.

Ascensao et al., 2011

The first article reviewed was published in Portugal and involved cold water immersion and recovery from muscle damage following a soccer game (Ascensao et al., 2011). Twenty male soccer players from two separate junior national league teams participated in this study. After the soccer game, the cold water treatment group was submerged to the iliac crest in 10°C water for 10 minutes. The control group performed the same protocol following the soccer match as the CWI group, but the water for the control group was 35°C instead of 10°C. After the treatment groups completed their respective protocols, the subjects were tasked with completing perceived muscle soreness questionnaires as well as venous blood samples being taken and performance test measures in jump and sprint tests. The authors found no significant differences between groups in the jump or spring performance measures. Higher levels of myoglobin and creatine kinase were found in the control group but perceived muscle soreness was decreased in the treatment

group compared to the control group. The authors concluded that the treatment was beneficial to an extent in reducing perceived muscle soreness following exercise in the soccer players of the treatment group.

Delextrat et al., 2013

A study involving basketball players from the United Kingdom titled “Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players” was reviewed (Delextrat et al., 2013). Eight male and eight female basketball players from the University Premier League were recruited for participation in the study. After completion of exercise in either a practice or simulated game format, the subjects were assigned to either the post-exercise massage group, cold water treatment group or the control group. Immediately after completion of the competitive game the massage group subjects received massage treatment from an experienced masseuse for 30 minutes of treatment on the legs. The cold water treatment group began CWI directly after exercise was completed with treatment involving five 2 minute intermittent immersions up to the iliac crest in 11°C water. The control group did not receive any treatment protocols following exercise. The authors found that perceived fatigue was lower in the massage group and CWI group following treatment compared to the control group (Delextrat et al., 2013). Women subjects in the CWI group also had lower perceived fatigue than women in the massage group. Perceived soreness was also lower in the massage and treatment groups post treatment compared to the control group (Delextrat et al., 2013). Cold water immersion performed directly after exercise reduced perceived fatigue and soreness in the participants within the study, especially the women subjects (Delextrat et al., 2013).

Elias et al., 2013

A study conducted in Australia was the next article reviewed which involved cold water immersion and Australian soccer players (Elias et al., 2013). This study involved 24 professional

soccer players which, after a match, were assigned to 1 of 3 recovery interventions. Variables measured in the athletes included repeat-sprint ability, static jump, countermovement jump, perceived soreness and perceived fatigue. After the completion of the match the cold water immersion group immediately began treatment by being submerged in 12°C water up to their xiphoid process for 14 minutes consecutively. The alternating therapy group also began their treatment after exercise by submerging themselves in water up to their xiphoid process for 1 minute in 12°C water followed immediately by submerging themselves in 38°C warm water for 1 minute to constitute a single cycle of which this group performed 7 total cycles. The control group participated in the exercise portion of the study but did not perform either of the recovery protocols. The authors found that the repeat-sprinting was slower for the control group and alternating therapy group compared to the cold water immersion group 24 hours after the treatments were concluded (Elias et al., 2013). Perceived soreness was most significantly reduced in the cold water immersion group compared to the control and alternating therapy groups. Perceived fatigue was also reduced in the cold water immersion group compared to the control and alternating therapy groups. Lastly, declines in static and countermovement jump performance were reduced by those participants in the cold water immersion group. As a result of these findings Elias and researchers concluded that cold water immersion was beneficial for helping soccer players recover from exercise and restore performance in sprint test and jump tests as well as performing better as a recovery protocol for perceived fatigue and soreness.

Vaile et al., 2008

A study involving strength trained males and cold water immersion to alleviate DOMS was the next article reviewed (Vaile et al., 2008). This article involved 38 strength trained males randomly assigned to either the control group, cold water immersion group, hot water immersion group or contrast water therapy group for treatment post exercise. The study utilized a randomized cross-over design so that each participant would experience each treatment protocol.

The subjects in the study performed seven sets of ten eccentric repetitions on a leg press machine in order to induce DOMS. This exercise protocol was conducted on two separate occasions eight months apart. Following each exercise protocol the subjects participated in their assigned recovery treatment, either control, cold water immersion, hot water immersion or contrast water therapy. The control consisted of no treatment, just sitting in place while the other groups performed treatment. The cold water immersion involved submersion up to the neck in 15°C water for 14 minutes. The hot water immersion treatment involved submersion up to the neck in 38°C water for 14 minutes. Finally, the contrast water therapy involved alternating between cold water exposure (15°C for 1 minute) and hot water exposure (38°C for 1 minute) to constitute a single cycle of which the contrast water therapy group performed 7 cycles. The effects of the exercise and treatment protocols were measured using perceived soreness questionnaire, isometric squat force and squat jump performance. The results showed that CWI and contrast water therapy reduced decreases in squat jump performance. CWI, hot water immersion and contrast water therapy all helped reduce decreases in isometric force compared to the control group. Perceived soreness was not significantly different between any of the treatment groups compared to the control. The authors concluded that cold water immersion and contrast water therapy were effective in reducing deficits both physiologically and performance based that were inflicted by DOMS (Vaile et al., 2008). Hot water therapy was also found to be effective for recovering isometric force following intense exercise compared to the control group (Vaile et al., 2008).

Ingram et al., 2009

The next study included in this review was conducted at the University of Western Australia and published in Australia (Ingram et al., 2009). Ingram and researchers observed 11 male athletes during simulated team sport exercise and shuttle run exercise designed to induce fatigue and muscle exhaustion. The first baseline measures for the athletes in this study were

recorded on the first day in the lab and included twenty meter sprint times, isometric strength tests for the quads, hamstrings and hip flexors of each athlete as well as a perceived muscle soreness questionnaire which finalized the baseline measurements. The next day in the lab, the athletes completed 80 minutes of simulated team sport exercise which included four 20 minute quarters of intermittent running. The final part of this day's exercise involved the subjects performing a twenty meter shuttle test to further exacerbate exercise fatigue. Once this was completed the 11 subjects again recorded their twenty meter sprint times, isometric strength tests and muscle soreness questionnaires. Following the exercise protocol the subjects reported to either the contrast water therapy treatment group, cold water immersion group or the control group. After treatment the subjects performed their final measures for the twenty meter sprint, isometric strength test and perceived muscle soreness questionnaire. The contrast water therapy protocol involved alternating 2 minutes in 10°C water followed immediately by 2 minutes in 40°C water to constitute a single round of which three rounds were performed (Ingram et al., 2009). The cold water immersion group was immersed in 10°C water for one 5 minute round followed by a slight rest period then finished with another 5 minute round of submersion with a total of 10 minutes spent in the cold tank (Ingram et al., 2009). The researchers discovered that the cold water immersion group had lower ratings of perceived soreness post exercise when compared to the contrast water therapy (CWT) group or control group (Ingram et al., 2009). Ingram & company also found that isometric strength measures declined considerably for the CWT and control group but not for participants in the cold water immersion group. Subjects in the cold water immersion group also reported less decline in their sprint tests post exercise when compared to the CWT group or the control. Ingram concluded that cold water immersion was the superior modality for post exercise recovery in this study compared to the CWT group or the control group due to the findings involving isometric strength, sprint test times and perceived soreness (Ingram et al., 2009).

Leeder et al., 2011

A meta-analysis conducted by Leeder et al., sought to provide insight into the research regarding CWI as a treatment modality (2011). Fourteen studies were included in the meta-analysis, including 239 subjects compiled from all the research cases (Leeder et al., 2011). The studies within the analysis were included because they either examined for effects of CWI on muscle power, muscle strength, muscle soreness (DOMS), and or CK (Leeder et al., 2011). The level of activity and athletic experience within the subject population ranged from untrained to elite athlete groups, with mean age being 23 years \pm 3 years (Leeder et al., 2011). CWI temperature ranged between 5°C-15°C with length of immersion ranging from 5 minutes to 24 minutes (Leeder et al., 2011). Exercise protocols designed to induce fatigue or muscle damage included shuttle tests, drop jumps, countermovement jumps, eccentric arm extensions, eccentric leg press, cycling, eccentric plantar flexion, and a basketball tournament (Leeder et al., 2011). The main findings of this meta-analysis were; CWI alleviated DOMS symptoms at 24, 48, 72, and 96 hours post exercise, CWI had a small effect in reducing CK post exercise, and lastly that CWI had no effect on recovery of muscle strength but was effective in improving recovery of muscle power (Leeder et al., 2011). This analysis provides a large body of research in one analysis for examination of CWI as a treatment method. The large variety in athlete age, experience, exercise protocol, and CWI duration and temperature provides much insight into the field of research regarding CWI, but more research is needed to further clarify questions regarding CWI as a recovery modality.

Alleviation from perceived soreness is perhaps the greatest scientifically supported proponent of CWI. Results have been somewhat inconsistent in the previous sections of this review regarding efficacy of CWI to effect CRP levels, myoglobin levels, CK levels, ROM, and MVC in a significant enough manner to warrant CWI as a recovery method. The scientific literature within this section, however, provides a very uniform set of findings. It was revealed

that CWI performed after a soccer game resulted in reduced perceived soreness in the treatment group compared to control during a study conducted in Portugal (Ascensao et al., 2011). Basketball players have also been study extensively by researchers in order to discover optimum recovery methods from practice and competition. Delextrat et al., discovered that perceived soreness was lower in the CWI treatment group compared to control following CWI treatment after a simulated basketball game (2013). Another study involving Australian soccer players revealed similar findings, in that perceived soreness was most significantly reduced in CWI group compared to a control or alternating therapy group (Elias et al., 2013). Some strength trained athletes however, have not seen significant reductions in perceived soreness as a result of CWI. Strength athletes that participated in leg press exercise intended to cause muscular fatigue, followed by CWI treatment post exercise, saw no significant reductions in perceived soreness compared to their control group counterparts (Vaile et al., 2008). Those findings disagree with Ingram and researchers, who discovered that simulated team sport exercise and shuttle runs followed by CWI treatment alleviated perceived soreness post exercise compared to contrast water therapy and the control group (2009). As portrayed, the studies within this section give evidence that CWI is effective in reducing perceived soreness. All but one of the studies within this section support the notion that CWI treatment is an effective modality in reducing perceived soreness caused by intense exercise.

Exercise Performance

It is common for athletes to seek a competitive edge when training, recovering or in actual sport performance over their competition in order to have the best chance for success. There is research that displays the efficacy of CWI treatment as an ergogenic aid (Ingram et al., 2009; Stanley, Peake & Buchheit, 2013; Elias et al., 2013;). There is also evidence that does not support CWI treatment as an effective modality for alleviating symptoms of intense exercise, improving markers of strength, or improving jump performance (Eston & Peters, 1999;

Skurvydas et al., 2006; Robey et al., 2009). More research is needed involving exercise performance measures and CWI treatment.

Stanley, Peake, & Buchheit, 2013

Stanley, Peake, and Buchheit sought to investigate the relationship between performance and heart rate variability over a multiple day exercise protocol including post-exercise CWI treatment (Stanley, Peake & Buchheit, 2013). Their study involved 11 cyclists that participated in two separate 3-day training blocks that involved a long distance component, max bicycle sprint component, and a short time trialing component preceded by 2 days of “recovery based training” (Stanley, Peake & Buchheit, 2013, p. 371). Recovery treatment was conducted 15 minutes after the exercise protocol by having the cyclists stand up to their necks in 10°C water for 5 minutes. The control was conducted 15 minutes after the exercise protocol as well by having the participants simply sit in a 27°C room for 5 minutes. Measurements taken from the subjects included mean power for sprints, total work and heartrate during every session. The study followed a randomized, counterbalanced, crossover design that ran 11 days and involved a training session followed by a specific recovery intervention on 3 consecutive days followed by two consecutive days of recovery training that caused the athletes to exert less than 60% of their VO₂ max on the first recovery training day and 75% on the second (Stanley, Peake & Buchheit, 2013). Baseline VO₂ max was recorded during the incremental exercise test on a cycle ergometer (Stanley, Peake & Buchheit, 2013). The authors study revealed that sprint cycling performance decreased less during the 3 day training block in the CWI treatment group compared to the control group (Stanley, Peake & Buchheit, 2013). The authors measured sprint cycling performance by analyzing average sprint power output, which decreased less for the CWI treatment group than the control group (Stanley, Peake & Buchheit, 2013). The authors went further to state that the CWI treatment group maintained “power and cadence during the sprints, a

faster recovery of neuromuscular function” was likely accomplished (Stanley, Peake & Buchheit, 2013).

Pournot et al., 2011

The sport of rugby commonly involves intense training or practice sessions with minimal or reduced recovery time (Pournot, Bieuzen, Duffield, Lepretre, Cozzolino, & Hausswirth, 2011). This can result in reduced performance as well as an increased chance of injury in rugby players. Pournot and company sought to analyze the effect differing CWI techniques conducted after exercise had on recovery and measures of athletic performance in 41 male rugby players (2011). Performance measures were recorded before the exercise portion of the experimental design began. Researchers measured maximal 30 second rowing power on a rowing ergometer, maximal counter-movement jump height (CMJ), MVC of the knee extensors using a maximal isokinetic dynamometer, CK, lactate dehydrogenase (LHD), and perceived soreness (Pournot et al., 2011). These measurable were observed pre-exercise, post-exercise, 1 hour post-exercise, and 24 hours post-exercise (Pournot et al., 2011). The subjects performed 20 minutes of intense exercise designed to induce exhaustion, followed by 15 minutes of pre-assigned recovery modality (Pournot et al., 2011). The exercise portion of the study involved two separate exercise circuits lasting 10 minutes each with a 10 minute rest in between the sessions (Pournot et al., 2011). The first 10 minute circuit involved a rowing focused regimen that included 30 seconds of counter movement jumps (frequency imposed: 0.7 Hz), 30 seconds of rest, 30 seconds of intense rowing conducted on a rowing ergometer at 80% of pre-established max rowing power, and finished with a 30 second rest period before being repeated again as many times as possible within the 10 minute time frame (Pournot et al., 2011). A ten minute rest period was observed before the same exhaustive exercise circuit was conducted a second time for 10 minutes (Pournot et al., 2011). Following completion of the second exercise circuit the participants began their 15 minute recovery modality that was randomly assigned before the study began. Recovery modalities

included: CWI in 10°C water to the iliac crest for 15 minutes, TWI (temperate water immersion) in 36°C water to the iliac crest for 15 minutes, CWT (contrast water temperature) in 10-42°C water to the iliac crest for 15 minutes, or the control condition which simply sat in a chair (Pournot et al., 2011). The researchers discovered that CWI resulted in a faster recovery of CMJ and MVC at the 1 hour post-exercise time mark compared to the control group and TWI (Pournot et al., 2011). It was also found that the CWI group had a blunted CK count 24 hours post-exercise compared to control, CWT, and TWI (Pournot et al., 2011). Pournot concluded that CWI following exercise was more effective in “force loss restoration” than TWI, CWT, or control (2011, p. 1294). Pournot also concluded that CWI offered remedy to inflammation brought on by exercise compared to CWT, TWI, or control (Pournot et al., 2011).

King & Duffield, 2009

Netball is a sport that involves high intensity sprint action similar to basketball, conducted over a 60 minute game span, and puts athletes or participants at a risk for muscle damage and soreness due to the physiological demands posed by the sport. (King & Duffield, 2009). This was the basis for a study completed in 2009 involving female netball players, exhaustive exercise, and the effect CWI treatment had on recovery and various markers of exercise performance and muscle function (King & Duffield, 2009). King and Duffield utilized a sample of 10 female athletes between the ages of 18-21 with a history of competitive netball experience (2009). The subjects were tested pre-exercise in maximal aerobic speed ($v\text{-VO}_2\text{max}$) utilizing 20-minute shuttle run test, countermovement vertical jumps, 10m sprint times, 20m sprint times, and perceived exertion (King & Duffield, 2009). The exercise protocol within the study was comprised of 4x15 minute intermittent sprint circuit sessions designed to induce muscular fatigue (King & Duffield, 2009). The exercise course was designed to mimic the demands of a netball match and included various agility movements, a 10m all out sprint, backpedals, and hurdles (King & Duffield, 2009). At the end of each quarter participants were

given a 3 minute break and at half-time a 5 minute break was allowed in order to accurately simulate the time demands of a netball match (King & Duffield, 2009). Post-exercise performance tests were immediately conducted upon completion of exercise protocol and included 5 countermovement jumps in 20 seconds and 5x20m sprints with 10m time and 20m time recorded in order to determine reductions in power and speed resulting from the exercise protocol (King & Duffield, 2009). After this the participants were assigned randomly to one of four recovery interventions including: CWI (10°C for 5 minutes to the iliac crest then 2.5 minute rest and another 5 minute session); CWT (10°C for 1 minute to the iliac crest then shower in 40°C water for 2 minutes repeated five times); control; or active recovery (ACT) involving low intensity exercise at 40% of previously established v-VO₂ max (King & Duffield, 2009). This entire procedure including warmup, pre-exercise performance measures, exercise protocol, post-exercise performance test, and treatment was conducted a second time 24 hours later (King & Duffield, 2009). No significant differences were found in 20m sprint times between session 1 and session 2 for any of the recovery treatments (King & Duffield, 2009). No significant differences were found in 10m sprint times or countermovement jump between session 1 and session 2 for any of the recovery modalities (King & Duffield, 2009). King and Duffield ultimately concluded that the data revealed no performance benefits following CWI, CWT, or ACT treatment post-exercise compared to control (2009).

This section, which covered research within the field involving CWI after exercise and the effect treatment had on measures of exercise performance, is perhaps the most relevant to determining CWI efficacy as a treatment modality. More than any of the other purported effects of CWI, exercise performance is the most important variable to athletes and coaches alike. If an athlete can improve his/her exercise performance utilizing CWI as a treatment, then efficacy for CWI is legitimized. The opposite can be said however, if CWI does not have any proven benefit for exercise performance. Cyclists studied during an exercise protocol involving bicycle sprints

followed by CWI post-exercise revealed that CWI subjects had decreased performance over the 3 day study, but to a significantly less degree than cyclists in the control group (Stanley, Peake, & Buchheit, 2013). This study revealed that in fact exercise performance was not improved via CWI, but decreases in bicycle sprint times were minimized by CWI as opposed to the control (Stanley, Peake, & Buchheit, 2013). Rugby players are a popular group of athletes within the scientific research community to study regarding CWI. Pournot et al., discovered that rugby players in the CWI treatment group had a faster recovery of CMJ and MVC to baseline measures at the 1 hour post-exercise and post-immersion time mark than athletes in the control group (2011). Athletes in the sport of netball have not benefitted from CWI as much as their cyclist and rugby counterparts. King and Duffield studied netball athletes and subjected them to intermittent sprint exercise and CWI post-sprint work (2009). No significant differences were found in sprint times recorded between session 1 and 2 for any of the recovery treatments (King & Duffield, 2009). Due to the inconclusive nature of the findings within these studies, more research is needed to fully determine if CWI provides a positive benefit on exercise performance.

Appendix F. IRB Approval Letter

Oklahoma State University Institutional Review Board

Date: Thursday, January 28, 2016
IRB Application No GC1519
Proposal Title: Estimating contributions of cold water immersion to recovery from exercise

Reviewed and Processed as: Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 1/27/2017

Principal Investigator(s):

Johnie Michael Jason DeFreitas
198 CRC
Stillwater, OK 74078 Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

- The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Scott Hall (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,


Dawnett Watkins, Chair
Institutional Review Board

VITA

JOHNIE KRITTENBRINK MICHAEL

Candidate for the Degree of

Master of Science

Thesis: ESTIMATING CONTRIBUTIONS OF CWI TO RECOVERY FROM
EXERCISE

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Completed the requirements for the Master of Science in Health & Human
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