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1 **Whole body cryotherapy, cold water immersion, or a placebo following resistance exercise: A case of**  
2 **mind over matter?**

3

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1 **ABSTRACT**

2 **Purpose:** The use of cryotherapy as a recovery intervention is prevalent amongst athletes. Performance of high  
3 volume, heavy load resistance exercise is known to result in disturbances of muscle function, perceptual responses  
4 and blood borne parameters. Therefore, this study investigated the influence of cold water immersion (CWI),  
5 whole body cryotherapy (WBC) or a placebo (PL) intervention on markers of recovery following an acute  
6 resistance training session.

7 **Methods:** Twenty four resistance trained males were matched into a CWI (10min at 10°C), WBC (3- and 4 min  
8 at -85°C) or PL group before completing a lower body resistance training session. Perceptions of soreness and  
9 training stress, markers of muscle function, inflammation and efflux of intracellular proteins were assessed before,  
10 and up to 72 h post exercise.

11 **Results:** The training session resulted in increased soreness, disturbances of muscle function, and increased  
12 inflammation and efflux of intracellular proteins. Although WBC attenuated soreness at 24 h, and positively  
13 influenced peak force at 48 h compared to CWI and PL, many of the remaining outcomes were trivial, unclear or  
14 favoured the PL condition. With the exception of CRP at 24 h, neither cryotherapy intervention attenuated the  
15 inflammatory response compared to PL.

16 **Conclusion:** There was some evidence to suggest that WBC is more effective than CWI at attenuating select  
17 perceptual and functional responses following resistance training. However, neither cryotherapy intervention was  
18 more effective than the placebo treatment at accelerating recovery. The implications of these findings should be  
19 carefully considered by individuals employing cryotherapy as a recovery strategy following heavy load resistance  
20 training.

21

22 **Keywords: Muscle Damage; Muscle Function; Inflammation; Resistance training**

23 **Abbreviations**

CK-M	Creatine Kinase-M
CMJ	Counter Movement Jump
CRP	C-Reactive Protein
CWI	Cold Water Immersion
DALDA	Daily Analysis of the Lifestyle Demands of Athletes
DXA	Dual X-ray Absorptiometry

ELISA	Enzyme-Linked Immunosorbent Assay
IL-6	Interleukin-6
MVIC	Maximal Voluntary Isometric Contraction
PL	Placebo
RFD	Rate of Force Development
RM	Repetition Maximum
RSI	Reactive Strength Index
TNF- $\alpha$	Tumour Necrosis Factor- $\alpha$
WBC	Whole Body Cryotherapy

## 1 INTRODUCTION

2 Exercise-induced muscle damage, most commonly resulting from unaccustomed or strenuous exercise, can lead  
3 to detrimental changes in perceptual responses, circulating intracellular proteins and functional capacity (Clarkson  
4 & Hubal, 2002). For athletes, any reduction in force producing ability, coupled with increases in muscle soreness  
5 could negatively impact upon subsequent training and performance (Khan et al., 2016). Therefore, the  
6 implementation of recovery interventions to expedite recovery is commonplace. Cryotherapy refers to the  
7 application of cold for therapeutic purposes, and its use as a means of accelerating recovery after strenuous  
8 exercise is becoming increasingly popular (Bleakley, Bieuzen, Davison, & Costello, 2014; Leeder, Gissane, van  
9 Someren, Gregson, & Howatson, 2012). Many top level athletes, coaches and practitioners have adopted  
10 cryotherapy as a potentially beneficial adjuvant to training. Whilst cold water immersion (CWI) remains an  
11 accessible modality requiring little equipment or specialist instruction, whole body cryotherapy (WBC) has been  
12 marketed as an alternative. There appears to be a perception that the extreme nature of WBC, which utilises far  
13 lower temperatures than CWI (-85°C to -125°C versus 10-15°C respectively) can offer enhanced benefits for  
14 recovery (Bleakley et al., 2014). The use of WBC continues to grow, and in some cases appears to be replacing  
15 more traditional cold therapies such as CWI (Costello, Donnelly, Karki, & Selfe, 2014; Savic, Fonda, & Sarabon,  
16 2013) for those individuals or teams who have access to the newer technology. There is a wealth of literature to  
17 suggest that CWI is effective at reducing delayed onset muscle soreness (DOMS) post exercise (Bleakley et al.,  
18 2012), but the influence on more functional markers of recovery such as strength, power and dynamic sporting  
19 movements remains less clear. Similarly, a review from Bleakley et al. (2014) found that whilst WBC can offer  
20 improvements in soreness and subjective recovery after exercise, there is little evidence of improvements in  
21 functional recovery.

22 Despite its growing popularity there is still very little available research directly comparing the different  
23 modalities or suggesting that WBC is any more effective than CWI as a recovery strategy following strenuous  
24 exercise. Abaïdia and colleagues (2016) compared the effectiveness of CWI and WBC on markers of recovery  
25 following an eccentric muscle damaging protocol. Their results showed that CWI was more effective for  
26 accelerating both functional and perceptual recovery post exercise compared to WBC. Whilst the findings add to  
27 the current body of literature, the unilateral eccentric exercise protocol used has little real world applicability to  
28 sports performance and therefore lacks ecological validity. Furthermore, muscle damaging exercise was carried  
29 out unilaterally, with conclusions about effectiveness based on bilateral vertical jump performance. A recent study

1 from Hohenauer and colleagues (2018) evaluated the effect of partial body cryotherapy and CWI on recovery  
2 following 5 x 20 drop jumps. Their findings suggested that although there was no treatment effect for soreness or  
3 functional recovery, there was a greater physiological response (assessed via cutaneous vascular conductance,  
4 thigh muscle oxygen saturation and lower extremity skin temperature) for CWI compared to partial body  
5 cryotherapy. These findings are supported by Mawhinney et al., (2017) who demonstrated that limb blood flow  
6 is reduced to a greater extent following CWI than WBC. Further, research from our group has evaluated the  
7 efficacy of CWI and WBC on performance following a trail marathon and found that WBC negatively impacted  
8 the recovery of muscle function compared to CWI, and that neither intervention was more effective than a placebo  
9 (Wilson et al., 2018). Presently, there do not appear to be any other studies directly comparing the effectiveness  
10 of the two different cryotherapy modalities on functional recovery after resistance exercise.

11 Minett & Costello (2015) highlight the need for specificity in the prescription of recovery interventions. It is well  
12 known that the mechanisms of muscle damage differ depending on the nature of the exercise stress (Armstrong,  
13 Warren, & Warren, 1991); whilst long duration endurance exercise is likely to result in predominantly metabolic  
14 damage (Tee, Bosch, & Lambert, 2007), resistance exercise can result in the breakdown of structural elements of  
15 muscle tissue and potentially greater functional perturbations. Therefore, the effectiveness of any recovery  
16 modality should be examined in relation to different exercise modes. The importance of resistance exercise as an  
17 adjunct to more traditional sport specific skills training is becoming more evident in competitive sport (Bartolomei,  
18 Hoffman, Merni, & Stout, 2014). Progressive, structured, heavy resistance training is no longer solely used by  
19 bodybuilders and weightlifters but also by team sport players, dancers, gymnasts and swimmers (Crowley,  
20 Harrison, & Lyons, 2017; Dowse, McGuigan, & Harrison, 2017). Therefore, it is pertinent to assess the influence  
21 of cryotherapy on markers of recovery following resistance training. Moreover, there is still scope to explore  
22 whether WBC and CWI exposures elicit different physiological responses and time courses of recovery (Hayter,  
23 Doma, Schumann, & Deakin, 2016) following strenuous exercise.

24 Furthermore, there appears to be increasing evidence that many of the therapeutic effects attributed to cryotherapy  
25 treatment may be due to a placebo effect (Broatch, Petersen, & Bishop, 2014; Wilson et al., 2018). Currently, the  
26 vast majority of cryotherapy studies have been conducted using a control group, and have not taken expectance  
27 effect or treatment belief into account when reporting study outcomes. Therefore, there is a need for future  
28 investigations to evaluate cryotherapy treatments in comparison to an effectively administered placebo  
29 intervention, rather than a control.

1 Hence, the main aim of this study was to compare the efficacy of CWI and WBC on recovery following strenuous  
2 resistance exercise, in order to try and address the current disparity in the literature. A further aim of this study  
3 was to use a holistic approach, encompassing performance, perceptual and blood borne markers, to establish  
4 whether either cryotherapy modality is any more effective than a placebo intervention following resistance  
5 exercise. It was hypothesised that CWI would be more beneficial for recovery than WBC, but that neither  
6 intervention would be more efficacious than a placebo treatment.

## 7 **METHODS**

### 8 **Participants**

9 A convenience sample of twenty four healthy male volunteers participated in this study (Table 1). Participants  
10 had no previous experience of cryotherapy and were required to have at least 12 months experience of strength  
11 training. All participants were non-smokers with no history of recent illness or lower limb injury. For 72 h prior  
12 to the baseline testing day and for the duration of the study, participants were asked to refrain from any additional  
13 strenuous exercise, and abstain from therapeutic treatments including massage and anti-inflammatory drugs, as  
14 well as any nutritional supplements.

15 \*\*\*INSERT TABLE 1 HERE\*\*\*

16

### 17 **Study Design**

18 All procedures were granted ethics approval by the Institutional committee according to the Helsinki declaration  
19 prior to testing. All participants received both written and verbal information about the purpose and potential  
20 risks of the proposed intervention. Participants gave their written informed consent and completed a  
21 comprehensive health questionnaire. Participants were matched into the placebo, CWI or WBC intervention group  
22 based on a ratio of their predicted 1RM back squat to lean mass assessed via DXA scan (fan beam, Lunar Prodigy  
23 4, GE Medical Systems, Lunar, Madison, WI, USA) (Roberts, Raastad, et al., 2015). Participants were familiarised  
24 with all testing procedures at least 72 h before the baseline session. At baseline, measures of all dependent  
25 variables were recorded before completion of the training session. Immediately after the training session a further  
26 blood sample was collected, and within 15 min participants commenced their allocated recovery intervention.  
27 Participants were also required to give blood samples at 60 and 120 min post intervention. Participants returned

1 to the laboratory to repeat measurements of all dependent variables at 24, 48 and 72 h following completion of  
2 the resistance training session.

### 3 **Daily Analysis of the Lifestyle Demands of Athletes (DALDA)**

4 Stress reaction symptoms were recorded using the DALDA questionnaire, and data from part 'B' is presented.  
5 The questionnaire has been used previously to monitor alterations in stress response following strenuous exercise  
6 and cryotherapy treatment (Wilson et al., 2018).

### 7 **Blood Sampling**

8 Whole blood samples were collected from the antecubital vein into 4 mL vacutainers for the purpose of assessing  
9 muscle damage and inflammation. Blood samples were then centrifuged at 3000 rpm for 8 min before being  
10 aliquoted and stored at -80°C for later analysis of creatine kinase-M (CK-M), interleukin 6 (IL-6), C reactive  
11 protein (CRP) and tumour necrosis factor- $\alpha$  (TNF $\alpha$ ). Blood samples were taken at baseline (CK-M, IL-6, CRP &  
12 TNF $\alpha$ ), immediately post training (IL-6 and TNF $\alpha$ ), 60 and 120 min post intervention (IL-6 and TNF $\alpha$ ), 24 (CK-  
13 M, IL-6, CRP & TNF $\alpha$ ), 48 and 72 h post (CK-M, CRP & TNF $\alpha$ ) post intervention (Leeder et al., 2014).

### 14 **CK-M**

15 Plasma CK-M concentrations were measured by simple step enzyme-linked immunosorbent assay (ELISA)  
16 (Abcam, Cambridge, UK). The reported assay ranges are 0.03 – 2.0 U/L, the minimum detection concentration  
17 (MDC) is 0.014 U/L, and the human serum intra- and inter-assay CVs were 3 and 9%, respectively.

### 18 **IL-6**

19 Plasma IL-6 concentration was determined using a quantitative sandwich (QS) ELISA (Quantikine, R&D Systems  
20 Europe Ltd., Abingdon, UK). The reported assay ranges are 3.1 - 300 pg/ml, the MDC is 0.7 mg/pl, and the intra-  
21 and inter-assay CVs were 2 and 3.8% respectively.

### 22 **CRP**

23 Plasma CRP concentration was determined using a QS ELISA technique (IBL International GmbH, Hamburg,  
24 Germany). The MDC for the assay was <1  $\mu$ g/ml with an intra and inter-assay CV of 5.12 and 14.3% respectively.

### 25 **TNF- $\alpha$**



1 Plasma TNF- $\alpha$  concentration was measured by QS-ELISA (BioVendor, Brno, Czech Republic). The reported  
2 assay ranges are 7.8 – 500 pg/ml, the MDC is 2.3 pg/ml, and the intra and inter-assay CVs were 6.0 and 7.4%  
3 respectively.

#### 4 **Perceived Soreness**

5 Participants indicated their perceived muscle soreness of the lower limbs during a body weight squat (approx.  
6 knee angle of 90°) using a 0 (no soreness on movement) to 10 (muscles too sore to move) Likert scale. This  
7 method has been used successfully in previous studies to monitor changes in perceptions of pain following  
8 exercise (Vaile, Gill, & Blazevich, 2007).

#### 9 **Peak Torque and Isometric Contractions**

10 Peak knee extensor torque and maximal voluntary isometric contraction (MVIC) were measured on the right limb  
11 using an isokinetic dynamometer (Biodex 3, Biodex Medical Systems, Shirley, NY, USA). Following a  
12 standardised warm-up, participants performed three x 3 sec MVICs of the knee extensors at a knee angle of 90°  
13 in accordance with previous studies (de Ruyter, van der Linden, van der Zijden, Hollander, & de Haan, 2003).  
14 Participants were then required to perform 3 maximal isokinetic efforts of the knee flexors and extensors at 60  
15 deg·s<sup>-1</sup>. Participants were encouraged to work as fast and as hard as possible against the resistance of the  
16 dynamometer arm throughout the full range of motion. The peak values were used for analysis.

#### 17 **Reactive Strength Index (RSI)**

18 Participants dropped from a platform at a height of 30 cm onto a portable force plate (Kistler, Switzerland) and  
19 then jumped vertically for maximum height as quickly as possible. Emphasis was placed on minimum ground  
20 contact time, whilst maintaining maximum jump height. Participants kept their hands on their hips for the duration  
21 of the movement, and performed 3 maximal jumps at each testing point. Reactive strength index (RSI) for each  
22 effort was calculated by dividing flight time by ground contact time (Flanagan & Comyns, 2008) and peak RSI  
23 values were used for statistical analysis.

#### 24 **Counter Movement Jump (CMJ)**

25 From a relaxed standing position on a portable force platform (Kistler, Switzerland), participants made a  
26 countermovement to a squat position (self-selected depth) before jumping vertically for maximal height. Each  
27 jump was performed in a continuous movement with hands remaining on hips for the duration. Three jumps were

1 recorded at each testing session. Any efforts that deviated from the prescribed technique were deemed void and  
2 repeated. Raw data was analysed in accordance with Chavda et al. (2017), and peak jump height values from each  
3 testing session were used for statistical analysis.

#### 4 **Isometric Squat**

5 Isometric squat parameters were measured using a portable force platform (Kistler, Switzerland), interfaced with  
6 a laptop and placed inside a custom designed rack (Absolute Performance, Cardiff, UK) allowing for adjustable  
7 bar height. For each participant, the bar was set in line with the base of their sternum, in an attempt to ensure that  
8 the isometric squat was performed in the mid-range of a back squat movement. The bar position was replicated at  
9 each testing session. Participants were asked to maintain a stable position under the bar whilst applying minimal  
10 pressure. Participants were asked to drive straight up as fast and as hard as possible against the bar and to maintain  
11 the contraction for 3 sec (Roberts et al., 2014). Three trials were completed at each testing session with a 3 min  
12 rest between efforts. If there was any sign of a visible countermovement, the trial was deemed void and repeated  
13 after a 3 min rest. Rate of force development was calculated from the force–time curve as the slope of the linear  
14 function from 100 to 200 milliseconds. Changes in the early phase of a contraction (<100 ms) can be attributed to  
15 fatigue or other neural factors, whilst changes in the later phase (>100 ms) tend to reflect alterations to contractile  
16 elements of skeletal muscle (Maffiuletti et al., 2016; Peñailillo, Blazevich, Numazawa, & Nosaka, 2015). The  
17 isometric peak force was determined as the maximal force recorded from each trial minus body mass. Peak  
18 isometric force was taken and used for analysis. The peak RFD value from 100-200 ms was used for analysis.

#### 19 **Exercise Protocol**

20 At the familiarisation session, predicted 1RM for the back squat, split squat, barbell hip thrust and Romanian  
21 deadlift was calculated for each participant. After completing a thorough warm up, participants were asked to  
22 select a load which they believed would elicit fatigue in 10 or fewer repetitions before being instructed to complete  
23 as many repetitions as possible. Loss of technique during any exercise was deemed as an unsuccessful lift. If the  
24 number of successful lifts exceeded 10 repetitions, participants rested for 15 min before attempting the exercise  
25 with an increased load. This was repeated for each of the 4 exercises and predicted 1RM was calculated using the  
26 Wathen prediction equation (Wathen, 1994). For the resistance training session, all exercises were performed at  
27 80% of the predicted 1RM for each exercise. The training session comprised 4 sets of 6 reps of back squats, 4  
28 sets of 8 reps of split squats, 4 sets of 8 reps of hip thrusts and 4 sets of 8 reps of Romanian deadlifts. This  
29 represented a total volume of 120 repetitions which is comparable to other studies utilising resistance exercise

1 and/or plyometrics to investigate recovery (Byrne & Eston, 2002; Jakeman, Byrne, & Eston, 2010), but offers a  
2 more ecologically valid exercise model to examine the efficacy of cryotherapy (Minett & Costello, 2015). Fifteen  
3 minutes after cessation of exercise, participants were asked to record a session RPE (Day, Mcguigan, Brice, &  
4 Foster, 2004) (Table 1.)

## 5 **Interventions**

### 6 **Whole Body Cryotherapy**

7 The WBC group were exposed to 2 cold treatments in a cryotherapy chamber (BOC, London, UK). Participants  
8 (up to 2 at a time) spent 3min in the chamber set to  $-85^{\circ}\text{C} \pm 5^{\circ}\text{C}$ . Participants then had a 15min warming period  
9 in an ambient room before entering the chamber for a further 4min bout at  $-85^{\circ}\text{C} \pm 5^{\circ}\text{C}$  (Wilson et al., 2018).  
10 Before entering the chamber participants were asked to remove glasses, contact lenses and any jewellery or  
11 piercings. During exposure, participants wore a pair of shorts and nothing above the waist, gloves, dry socks and  
12 shoes, a hat covering the ears and a mask to protect the nose and mouth.

### 13 **Cold Water Immersion**

14 Immediately after cessation of exercise participants sat in a mobile ice bath (iSprint Twin, iCool, Cranlea, UK)  
15 ensuring their lower limbs and iliac crest were fully immersed. Participants remained in the ice bath filled with  
16 water cooled to 10 degrees ( $\pm 0.5^{\circ}$ ) for 10 min. The ice bath was connected to a chiller unit (MiCool, iCool,  
17 Cranlea, UK) so that water temperature could be monitored and maintained within the desired parameters for the  
18 duration of the treatment. During exposure participants wore shorts and immediately after they were asked to  
19 towel themselves dry and change into clean, dry clothing. This protocol is comparable to those utilised in other  
20 single exposure studies examining the effects of CWI on various measures of recovery (Ascensão, Leite, Rebelo,  
21 Magalhães, & Magalhães, 2011; Roberts et al., 2014).

### 22 **Placebo**

23 As it was not possible to blind participants to their recovery intervention, a placebo, rather than a control group  
24 was used. Branched chain amino acids (BCAAs) are commonly used by athletes and have been shown to  
25 accelerate recovery following resistance training (Norton & Layman, 2006). Therefore, participants in the placebo  
26 group were given a cornstarch pill and informed that they were taking a BCAA supplement after the training  
27 session. Participants were asked to rest quietly for 10 min following completion of the training session. It was

1 hoped that the use of a placebo (sham) group would minimise associated placebo effects (i.e. effects of the  
2 treatment that were not related to the treatment itself) (McClung & Collins, 2007).

### 3 **Statistical Analysis**

4 Confidence limits (CL) and magnitude based inferences were calculated for each dependent variable using  
5 methods described by Batterham and Hopkins (2006). The smallest practically worthwhile effect for muscle  
6 function and blood parameters was the smallest standardised (Cohen) change in the mean: 0.2 times the between-  
7 subject SD for baseline values of all participants (Batterham & Hopkins, 2006). The smallest worthwhile change  
8 for muscle soreness and DALDA scores was a change in raw values of 1.0 (Hopkins, 2015). In order to account  
9 for large inter-individual differences in blood parameters, baseline values were used as a covariate. Qualitative  
10 descriptors relate to the likelihood of increased, trivial or decreased outcomes. Clinical inferences were based on  
11 threshold chances of harm and benefit of 0.5 and 25% respectively. In cases where the inference was unclear, a  
12 beneficial inference was reported where the odds ratio of benefit/harm was greater than 66. In order to overcome  
13 heteroscedastic error, the analysis of dependent variables was conducted on log-transformed data (Nevill & Lane,  
14 2007), except in the cases of muscle soreness and DALDA. Interval scaling makes it inappropriate to log-  
15 transform data for these variables (Nevill & Lane, 2007) so analysis was conducted on raw values. Each dependent  
16 variable was analysed using a published spreadsheet by Hopkins (2015). Changes are reported as percentages for  
17 function variables, raw changes for perceptual variables and factor changes for blood markers. Effect sizes are  
18 reported in addition to magnitude based inferences, where 0.0-0.19 is trivial, 0.20-0.59 is small, 0.60-1.19 is  
19 moderate, 1.20-1.99 is large, 2.0-3.99 is very large and 4.0+ is extremely large (Hopkins, Marshall, Batterham, &  
20 Hanin, 2009). P values for the main interaction effects (time x group), determined using a factorial ANOVA with  
21 repeated measures on 1 factor (time), have also been stated. When the main effect was significant, an LSD adjusted  
22 post-hoc test was used to investigate between-group differences at specific time points.

23

### 24 **Results**

25 The outcomes for changes over time as well as group comparisons for all parameters can be seen in tables 2 and  
26 3, and figure 1. The resistance exercise session resulted in increased perceptions of soreness and stress reaction  
27 symptoms, decreases in muscle function and increases in markers of structural damage and inflammation.

### 28 **DALDA**

1 At baseline, DALDA values were  $4 \pm 6$ ,  $1 \pm 1$  and  $2 \pm 2$  scores marked as worse than normal for placebo, CWI  
2 and WBC respectively. Scores marked worse than normal peaked at 24 h for the placebo group and at 48 h for  
3 both cryotherapy groups. CWI demonstrated greater increases compared to placebo at all time points. Scores were  
4 greater for WBC compared to the placebo at 48 h, but demonstrated a beneficial effect compared to the placebo  
5 at 24 h. All other group comparisons were trivial or unclear. The  $p$  value for the main interaction effect was 0.742.

## 6 **Perceived soreness**

7 At baseline, soreness values were  $1 \pm 1$ ,  $1 \pm 1$  and  $2 \pm 2$  (VAS 0-10) for placebo, CWI and WBC respectively.  
8 Perceptions of soreness increased in all groups; scores remained elevated in the placebo and CWI groups, but  
9 returned to baseline levels in the WBC group at 72 h post. WBC elicited smaller increases compared to both  
10 placebo and CWI at 24 h, but comparisons were unclear at 48 and 72 h post. CWI demonstrated a trivial effect  
11 compared to placebo at all time points. The  $p$  value for the main interaction effect was 0.061.

12 \*\*\*INSERT TABLE 2 HERE\*\*\*

## 13 **Peak Torque and Isometric Contractions**

### 14 *MVIC 90°*

15 At baseline, MVIC values at 90° were  $273.60 \pm 57.76$ ,  $255.00 \pm 63.17$  and  $240.59 \pm 69.74$  N for placebo, CWI  
16 and WBC respectively. MVIC was reduced at all time points in all groups. CWI demonstrated greater decrements  
17 compared to placebo at 24 and 48 h post, whilst WBC was trivial compared to placebo at 24 h. Comparisons  
18 between CWI and WBC were unclear at all time points. The  $p$  value for the main interaction effect was 0.714.

### 19 *Peak Torque 60deg·s<sup>-1</sup>*

20 At baseline, peak torque values at 60deg·s<sup>-1</sup> were  $223.54 \pm 50.65$ ,  $207.18 \pm 38.85$  and  $194.98 \pm 37.61$  for placebo,  
21 CWI and WBC respectively. Changes in peak torque values at 60deg·s<sup>-1</sup> for the placebo group were trivial at all  
22 time points, but demonstrated a decrease in both cryotherapy groups between baseline and 24 h, and decreases or  
23 trivial changes between baseline and 48 h and baseline and 72 h. Group comparisons demonstrated that at 24 h,  
24 values for both CWI and WBC were reduced compared to the placebo group, as a result of trivial changes in the  
25 placebo group. The  $p$  value for the main interaction effect was 0.054.

## 26 **RSI**

1 At baseline, RSI values were  $1.80 \pm 0.28$ ,  $2.20 \pm 0.31$  and  $2.07 \pm 0.31$   $\text{cm}\cdot\text{s}^{-1}$  for placebo, CWI and WBC  
2 respectively. For the placebo and CWI groups, all changes over time demonstrated decreased or unclear effects,  
3 and for WBC, there was a possible improvement at 24 h post, but a decrease at both 48 and 72 h post. Cryotherapy  
4 was unclear, or less effective compared to placebo at all time points, with the exception of WBC at 24 h which  
5 showed a likely improvement. The  $p$  value for the main interaction effect was  $<0.001$ . Post-hoc analyses revealed  
6 significant differences between WBC and placebo, and WBC and CWI at 24 h ( $p < 0.05$ ).

## 7 **CMJ**

8 At baseline, CMJ height values were  $0.35 \pm 0.06$ ,  $0.34 \pm 0.04$  and  $0.40 \pm 0.05$  m for placebo, CWI and WBC  
9 respectively. The exercise bout resulted in decreased CMJ performance for all groups at all time points. The  
10 greatest decrements in performance were evident at 24 h post for placebo and WBC, and at 48 h post for CWI. In  
11 terms of group comparisons, WBC demonstrated a greater decrement compared to CWI at 24 h, but unclear, and  
12 trivial effects at 48 and 72 h respectively. When compared to the placebo intervention, CWI showed greater  
13 decrements at 48 and 72 h, whilst WBC showed greater decrements at both 24 and 72 h post. The  $p$  value for the  
14 main interaction effect was 0.714.

## 15 **Isometric squat**

### 16 *Isometric Peak Force*

17 At baseline isometric peak force values were  $1620.43 \pm 330.01$ ,  $1693.36 \pm 398.76$  and  $1763.01 \pm 682.02$  Nm for  
18 placebo, CWI and WBC respectively. Peak performance perturbations were evident at 48 h post for all groups.  
19 All group comparisons at 24 and 72 hours were either unclear or trivial. However, at 48 h CWI showed a reduction  
20 compared to placebo, and WBC was improved compared to CWI and placebo. The  $p$  value for the main interaction  
21 effect was 0.018. Post-hoc analyses revealed significant differences between CWI and WBC at 48 h ( $p < 0.05$ ).

### 22 *RFD 100-200ms*

23 At baseline, RFD values between 100 and 200 ms were  $4866.78 \pm 1889.46$ ,  $5022.59 \pm 1081.36$  and  $4135.02 \pm$   
24  $1756.94$   $\text{Nm}\cdot\text{s}^{-1}$  for placebo, CWI and WBC respectively. Decrements in performance were most pronounced at  
25 24 h for WBC, and at 48 h for placebo and CWI. WBC demonstrated an improvement compared to CWI and  
26 placebo at 48 h, but comparisons were unclear at 72 h. WBC demonstrated a reduction in performance compared  
27 to the placebo at 24 h, and performance in the CWI group was reduced compared to the placebo at all time points.

1 The  $p$  value for the main interaction effect was  $<0.001$ , although post-hoc analyses revealed no significant group  
2 interactions.

3 \*\*\*INSERT TABLE 3 HERE\*\*\*

#### 4 **Bloods**

##### 5 *CK-M*

6 At baseline, CK-M values were  $79.7 \pm 27.6$ ,  $145.7 \pm 184.8$  and  $253.2 \pm 249.9$  U/L for placebo, CWI and WBC  
7 respectively. Increases were most pronounced at 24 h in all groups (most likely very large (4.66;  $x/\div 1.21$ ), most  
8 likely large (4.02;  $x/\div 1.63$ ) and most likely moderate (4.63;  $x/\div 1.41$ ) increases for PL, CWI and WBC  
9 respectively), and had not returned to baseline levels by 72 h in any group. Comparisons for the CWI group were  
10 unclear compared to placebo at 24 and 48 h, but demonstrated a possibly small increase at 72 h (1.20;  $x/\div 1.45$ ).  
11 WBC demonstrated a trivial effect compared to placebo at 24 h, but a possibly moderate (1.44;  $x/\div 1.69$ ) and likely  
12 large (1.57;  $x/\div 1.40$ ) increase at 48 and 72 h respectively. For comparison between cryotherapy modalities, WBC  
13 demonstrated a possibly small (1.15;  $x/\div 1.73$ ), likely moderate (1.61;  $x/\div 1.94$ ), and possibly moderate (1.31;  
14  $x/\div 1.51$ ) increase compared to placebo at 24, 48 and 72 h respectively. The  $p$  value for the main interaction effect  
15 was 0.457.

##### 16 *IL-6*

17 At baseline, IL-6 values were  $778.4 \pm 2015.8$ ,  $25.9 \pm 27.2$  and  $16.5 \pm 27.8$  pg/ml for placebo, CWI and WBC  
18 respectively. Change over time revealed trivial effects for all groups at all time points with the exception of WBC  
19 immediately- and 120 min post, where there were possibly small increases (1.78;  $x/\div 1.78$  and 1.76;  $x/\div 1.53$   
20 respectively). All group comparisons were trivial at all time points. The  $p$  value for the main interaction effect  
21 was 0.437.

##### 22 *CRP*

23 At baseline, CRP values were  $1567.1 \pm 2861$ ,  $1126.4 \pm 1071.9$  and  $358.4 \pm 220.8$   $\mu\text{g/ml}$  for placebo, CWI and  
24 WBC respectively. From baseline to 24 h, change over time analyses revealed a very likely small (2.43;  $x/\div 1.54$ )  
25 and possibly likely small (1.29;  $x/\div 1.26$ ) increase for PL and CWI respectively whilst WBC demonstrated a very  
26 likely moderate increase (1.95;  $x/\div 1.51$ ). At 48 h, both PL and CWI revealed a trivial change, whilst WBC  
27 demonstrated a likely moderate increase (2.06;  $x/\div 1.65$ ). At 72 h PL and CWI demonstrated an unclear effect

1 whilst there was a possibly moderate increase (1.51;  $x/\pm 1.69$ ) for WBC. From baseline to 24 h CWI values  
2 demonstrated a likely large decrease compared to placebo (0.53;  $x/\pm 1.59$ ), whilst comparisons at 48 and 72 h were  
3 unclear. WBC demonstrated an unclear effect compared to placebo at 24 h, but a possibly moderate increase at  
4 48 (1.53;  $x/\pm 1.85$ ) and 72 h (1.62;  $x/\pm 2.00$ ). WBC demonstrated a likely moderate increase compared to CWI at  
5 all time points (1.52;  $x/\pm 1.56$ , 2.04;  $x/\pm 1.88$  and 1.89;  $x/\pm 1.86$  at 24, 48 and 72 h respectively). The  $p$  value for  
6 the main interaction effect was 0.377.

#### 7 *TNF- $\alpha$*

8 At baseline, TNF- $\alpha$  values were  $38.7 \pm 28.6$ ,  $35.7 \pm 24.6$  and  $32.1 \pm 34.7$  pg/ml for placebo, CWI and WBC  
9 respectively. The time course of response differed amongst groups; peak values were recorded at 120 min, 72 h  
10 and 48 h post for placebo, CWI and WBC respectively. Change over time analyses revealed unclear or trivial  
11 effects for PL at all time points. CWI showed a small increase immediately post (1.39;  $x/\pm 1.92$ ), an unclear, and  
12 then trivial change at 60 and 120 min. There was a likely moderate decrease for CWI at 24 h (0.39;  $x/\pm 2.71$ ), an  
13 unclear change at 48 h and a likely moderate increase (1.90;  $x/\pm 1.84$ ) at 72 h. Changes for WBC were trivial or  
14 unclear at all time points with the exception of a possibly small increase (1.60;  $x/\pm 1.99$ ) immediately post and a  
15 likely small increase (1.85;  $x/\pm 1.91$ ) at 48 h. CWI demonstrated a likely moderate increase (2.23;  $x/\pm 3.59$ )  
16 compared to placebo immediately post, and a possibly small (1.48;  $x/\pm 3.62$ ), and likely moderate (2.43;  $x/\pm 2.15$ )  
17 increase compared to placebo at 48 and 72 h respectively. Compared to placebo, WBC demonstrated a likely  
18 moderate increase (2.56;  $x/\pm 3.640$ ) immediately post, a possibly small increase (1.52;  $x/\pm 2.73$ ) at 60 min post and  
19 a likely large increase (3.94;  $x/\pm 3.51$ ) at 48 h. Compared to CWI, WBC demonstrated a possibly trivial increase  
20 (1.15;  $x/\pm 2.40$ ) immediately post, a possibly small increase (1.41;  $x/\pm 3.55$ ) at 60 min, and a likely moderate  
21 increase at 120 min (2.59;  $x/\pm 5.04$ ), 24 h (2.86;  $x/\pm 4.17$ ) and 48 h (2.66;  $x/\pm 2.46$ ). All other group comparisons  
22 were unclear. The  $p$  value for the main interaction effect was 0.553.

23 \*\*\*INSERT FIGURE 1 HERE\*\*\*

24 Where there are large differences in baseline values between groups, this is attributed to one or two individuals  
25 who had values substantially greater than the normal range. However, as data was covariated using baseline values  
26 and results are analysed as the difference between groups in change over time, these participants were not removed  
27 from the analysis.

#### 28 **DISCUSSION**



1 The present study examined the effectiveness of a single bout of CWI or WBC, or a placebo intervention on  
2 markers of recovery in resistance trained males following a high volume, heavy load lower body resistance  
3 training session. The training session resulted in perturbations of muscle function, increases in perceptions of  
4 soreness and stress response symptoms and increases in blood borne markers of damage and inflammation.  
5 Overall, the results demonstrated little evidence to suggest that either cryotherapy intervention was more effective  
6 than a placebo at limiting decrements in muscle function, perturbations in perceptual responses or increases in  
7 inflammatory markers. Similarly, the majority of comparisons between CWI and WBC showed trivial or unclear  
8 results, although there was some evidence to suggest that WBC is more effective than CWI at attenuating  
9 detrimental increases in perceptual responses 24 post exercise, and that CWI may have greater potential for  
10 reducing inflammation compared to WBC.

11 For both cryotherapy interventions, DALDA scores were unclear, trivial or increased compared to the placebo  
12 intervention at all time points. However, from baseline to 24 h, WBC demonstrated a likely beneficial effect  
13 compared to CWI. These findings are supported by Wilson et al., (2018) who reported that whilst neither CWI or  
14 WBC offered any perceptual benefit over a placebo intervention, WBC was superior to CWI when monitoring  
15 recovery following a marathon. These findings lend further support to the suggestion that many of the therapeutic  
16 effects attributed to cryotherapy interventions may in fact be ascribed, at least in part, to a placebo effect (Broatch et  
17 al., 2014). In terms of muscle soreness, CWI showed a trivial effect compared to the placebo intervention at all  
18 time points, but from baseline to 24 h WBC was likely beneficial compared to both the placebo and CWI condition.

19 Maximal isometric strength at 90° decreased in all groups following completion of the resistance training session  
20 and remained diminished at 72 h. Group comparisons revealed trivial or unclear effects of WBC compared to  
21 placebo and CWI at all time point. For MVIC at 90°, CWI demonstrated moderate and small reductions compared  
22 to placebo at 24 and 48 h respectively. Similarly, in terms of peak force assessed via maximal isometric squats,  
23 despite all group comparisons being unclear at 24 and 72 h, CWI demonstrated a large performance reduction  
24 compared to moderate reduction in the placebo group at 48 h. These findings are in contrast to Vaile, Halson, Gill,  
25 & Dawson, (2008) who reported smaller peak force performance decrements in the CWI group (-7.3%) compared  
26 to a passive recovery group (-15.7%) following a DOMS-inducing eccentric leg press protocol. Methodological  
27 differences may help to explain the opposing findings. In the present study, participants completed a higher  
28 volume training session (120 versus 70 repetitions) which may have resulted in greater muscle damage, evidenced  
29 by greater peak force decrements at 48 h (-29.8 vs -7.3% for CWI and -18.8 vs -15.7% for placebo/control).

1 Secondly, the CWI intervention used in the study by Vaile and colleagues (2008) implemented a 14 min 15°C  
2 protocol whereas the present study utilised a 10 min 10°C protocol. This reaffirms the recommendation from  
3 Machado and colleagues (2016) that CWI at a temperature between 11 and 15°C for 11–15 min may provide the  
4 best results for both immediate and delayed effects. Further, as is becoming more important in cryotherapy  
5 literature (Broatch et al., 2014; Wilson et al., 2018), the present study employed a placebo, rather than a control  
6 group which may strengthen the study design and provide greater ecological validity. RFD is considered a more  
7 specific and sensitive indirect measure (Maffiuletti et al., 2016; Peñailillo et al., 2015) of muscle damage after  
8 exercise than MVIC. The RFD data from 100-200 ms largely mirrors the peak force data, suggesting that WBC  
9 was most beneficial at 48 h compared to CWI and placebo. However, unlike the peak force data, WBC  
10 demonstrated a reduced effect compared to the placebo at 24 h, so without further data the potential beneficial  
11 effects of WBC on peak force and RFD at specific time points should be interpreted cautiously.

12 For peak torque at 60 deg·s<sup>-1</sup> both cryotherapy interventions attenuated recovery compared to the placebo at 24 h.  
13 Further, CWI demonstrated a reduced recovery response compared to the placebo at 48 h. Comparisons between  
14 CWI and WBC were trivial or unclear at all time points, which is in contrast to Wilson et al., (2018) who found  
15 that recovery in WBC was reduced compared to CWI following a trail marathon. The selection of any outcome  
16 variable utilised to assess recovery after exercise should be specific to the exercise stress itself, and a time trial  
17 (although methodologically challenging) may have been more appropriate in the previous investigation. For this  
18 reason, peak torque values reported in the previous study may not accurately represent performance decrements  
19 following a prolonged endurance exercise stress.

20 Cryotherapy had a trivial or reduced impact on recovery of CMJ compared to the placebo at all time points.  
21 However, at 24 h WBC was possibly reduced compared to CWI, and this finding is supported by Abaïdia et al.,  
22 (2016) who reported that there was a very likely moderate effect in favour of CWI for CMJ recovery compared  
23 to WBC 72 h after exercise. A recent investigation from Hohenauer et al., (2018) demonstrated that there was no  
24 difference between CWI and partial body cryotherapy for functional recovery assessed via MVCs and vertical  
25 jumps. However, it is worth noting that neither study employed a placebo or control condition, so  
26 recommendations relating to the efficacy of cryotherapy should be interpreted with caution. Furthermore, differing  
27 exercise stresses (dynamometry and repeated drop jumps respectively) make it difficult to directly compare  
28 findings to the present investigation. In terms of RSI derived from the drop jump data, both cryotherapy  
29 interventions demonstrated a reduced or unclear effect compared to the placebo intervention. However, in contrast

1 to the jump height data, WBC was most likely beneficial compared to CWI at 24 h. This result may indicate the  
2 influence of a learning effect from baseline to the 24 h post testing session. Change over time analyses show that  
3 RSI values in the WBC group demonstrated a possibly beneficial effect at 24 h, whereas there was a decrease in  
4 both the placebo and CWI group at the same time point.

5 The finding that cryotherapy was ineffective at attenuating increases in CK following exercise is supported by  
6 Jakeman, Macrae & Eston, (2009) who reported that despite peaking 24 h following plyometric exercise, there  
7 were no differences in CK between the CWI and control group. Similarly, the results are supported by Wilson et  
8 al., (2018) who reported that following completion of a trail marathon WBC was less effective than CWI at  
9 tempering increases in CK.

10 A key mechanism purported to support the use of cryotherapy as a recovery intervention is that it can modulate  
11 blood flow and cell metabolism (Mawhinney et al., 2017), resulting in an attenuated inflammatory response  
12 (Tipton, Collier, Massey, Corbett, & Harper, 2017). The results from the present study do not support this premise,  
13 with cryotherapy largely trivial or less effective compared to the placebo intervention. In line with previous  
14 research, IL-6 peaked immediately post exercise (Roberts et al., 2014), however, all group comparisons were  
15 trivial, suggesting very little difference between interventions. Given that IL-6 is an acute phase inflammatory  
16 marker that often peaks immediately post exercise, it is possible that cryotherapy applied following exercise can  
17 have little impact on circulating levels. This is in line with Selfe et al., (2014) who reported that a single WBC  
18 exposure, irrespective of duration (1, 2 or 3 min), did not significantly alter circulating IL-6 following a game of  
19 rugby league. The results from the CRP and TNF- $\alpha$  analyses demonstrated that CWI may offer slight benefits  
20 compared to WBC, but that there was no benefit of cryotherapy compared to the placebo intervention. These  
21 findings are supported by White, Rhind, & Wells, (2014) who reported that CWI (10° x 10 min) following high  
22 intensity exercise does not reduce plasma markers of inflammation, and that prolonged CWI (10° x 30 min) can  
23 actually exacerbate the inflammatory response. Similarly, previous research has suggested that ‘severe cold’  
24 immersion protocols (5-10°) can negatively impact upon recovery, by eliciting a cold related stress response  
25 (Machado et al., 2016). This in turn could escalate the inflammatory cascade response, increase perceptions of  
26 soreness and ultimately impact on functional recovery (Machado et al., 2016; Wilson et al., 2018).

27 Potential limitations of the current study should also be addressed. The WBC treatment temperature utilised in the  
28 present study was considerably warmer than that normally reported in the literature (-85° versus -110° to -140°),  
29 therefore, although the findings add to the current body of literature, the findings cannot be generalised to colder

1 exposure temperatures. Secondly, there were large variations in baseline values for a number of outcome measures.  
2 For the blood markers, all results are reported as factor change over time and baseline values were used as a  
3 covariate. All participants avoided strenuous exercise for a minimum of 48 h before the baseline session, and it is  
4 likely that large variations are present in physically active populations. The pattern and magnitude of change was  
5 not largely different in participants who had large baseline values, compared to those with lower values.  
6 Participants were matched into groups based on lean mass and predicted 1RM, and as a result there were  
7 differences in absolute strength between groups. However, all functional outcomes were reported as percentage  
8 change to minimise the potential confounding effect of absolute raw values. Lastly, there was no direct measure  
9 of expectance effect or treatment belief in the present study. The authors acknowledge this as a limitation and  
10 appreciate that inclusion of this information may have strengthened the findings.

## 11 **CONCLUSION**

12 When comparing the efficacy of the different cryotherapy modalities on recovery following resistance training,  
13 although WBC demonstrated some beneficial effects compared to CWI, comparisons were largely unclear, trivial  
14 or favoured the CWI condition. These findings, in addition to those from Abaïdia et al., (2016) and Wilson et al.,  
15 (2018) add more weight to the argument that WBC offers few additional benefits over CWI for recovery  
16 following strenuous exercise. Similarly, in terms of investigating the contribution of a potential placebo effect  
17 associated with cryotherapy, the majority of group comparisons revealed unclear, trivial or unfavourable effects  
18 of cryotherapy compared to the placebo intervention, contradicting much of the previous literature. Again, this  
19 echoes the findings from Wilson et al., (2018) and highlights the need for future cryotherapy studies to implement  
20 an effective placebo controlled design. Similarly, further research is warranted to better understand treatment  
21 belief and expectance effects amongst athletes prior to implementing any recovery strategy. By using a more  
22 ecologically valid exercise stress than some of the previous resistance exercise literature (Fulford, Eston,  
23 Rowlands, & Davies, 2015; McLeay et al., 2012), it is hoped that the results may be more applicable to real world  
24 scenarios.

## 25 **Conflicts of Interest and Source of Funding**

26 No external funding was received for this work. The authors declare no conflict of interest.

27

## 28 **REFERENCES**

- 1 Abaïdia, A. E., Lamblin, J., Delecroix, B., Leduc, C., McCall, A., Nédélec, M., ... Dupont, G. (2016). Recovery  
2 From Exercise-Induced Muscle Damage: Cold Water Immersion Versus Whole Body Cryotherapy.  
3 *International Journal of Sports Physiology and Performance*, 1–23. <http://doi.org/10.1123/ijsp.2015->  
4 0012
- 5 Armstrong, R. B., Warren, G. L., & Warren, J. A. (1991). Mechanisms of Exercise-Induced Muscle Fibre  
6 Injury. *Sports Medicine*, 12(3), 184–207. <http://doi.org/10.2165/00007256-199112030-00004>
- 7 Ascensão, A., Leite, M., Rebelo, A. N., Magalhães, S., & Magalhães, J. (2011). Effects of cold water immersion  
8 on the recovery of physical performance and muscle damage following a one-off soccer match. *Journal of*  
9 *Sports Sciences*, 29(3), 217–225. <http://doi.org/10.1080/02640414.2010.526132>
- 10 Bartolomei, S., Hoffman, J. R., Merni, F., & Stout, J. R. (2014). A comparison of traditional and block  
11 periodized strength training programs in trained athletes. *The Journal of Strength & Conditioning*  
12 *Research*, 28(4), 990–997.
- 13 Batterham, A. M., & Hopkins, W. G. (2006). Making Meaningful Inferences About Magnitudes. *International*  
14 *Journal of Sports Physiology and Performance*, 1(1), 50–57.
- 15 Bleakley, C. M., Bieuzen, F., Davison, G. W., & Costello, J. T. (2014). Whole-body cryotherapy: empirical  
16 evidence and theoretical perspectives. *Open Access Journal of Sports Medicine*, 5, 25–36.  
17 <http://doi.org/10.2147/OAJSM.S41655>
- 18 Bleakley, C., McDonough, S., Gardner, E., Baxter, G. D., Ty, J., & Davison, G. W. (2012). Cold water  
19 immersion cryotherapy for preventing and treating muscle soreness after exercise. *Cochrane Database of*  
20 *Systematic Reviews*, (2). <http://doi.org/10.1002/14651858.CD008262.pub2>. Copyright
- 21 Broatch, J. R., Petersen, A., & Bishop, D. J. (2014). Postexercise Cold Water Immersion Benefits Are Not  
22 Greater than the Placebo Effect. *Medicine & Science in Sports & Exercise*, 46(11), 2139–2147.  
23 <http://doi.org/10.1249/MSS.0000000000000348>
- 24 Byrne, C., & Eston, R. (2002). The effect of exercise-induced muscle damage on isometric and dynamic knee  
25 extensor strength and vertical jump performance. *Journal of Sports Sciences*, 20(5), 417–25.  
26 <http://doi.org/10.1080/026404102317366672>

- 1 Chavda, S., Bromley, T., Jarvis, P., Williams, S., Bishop, C., Turner, A. N., ... Mundy, P. D. (2017). Force-time  
2 Characteristics of the Countermovement Jump: Analyzing the Curve in Excel. *Strength & Conditioning*  
3 *Journal*.
- 4 Clarkson, P. M., & Hubal, M. J. (2002). Exercise-induced muscle damage in humans. *American Journal of*  
5 *Physical Medicine & Rehabilitation / Association of Academic Physiatrists*, 81(11 Suppl), S52–S69.  
6 <http://doi.org/10.1097/01.PHM.0000029772.45258.43>
- 7 Costello, J. T., Donnelly, A. E., Karki, A., & Selfe, J. (2014). Effects of Whole Body Cryotherapy and Cold  
8 Water Immersion on Knee Skin Temperature. *International Journal of Sports Medicine*, 35(1), 35–40.  
9 <http://doi.org/10.1055/s-0033-1343410>
- 10 Crowley, E., Harrison, A. J., & Lyons, M. (2017). The Impact of Resistance Training on Swimming  
11 Performance: A Systematic Review. *Sports Medicine*, 1–23.
- 12 Day, M. L., Mcguigan, M. R., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance  
13 training using the session RPE scale. *The Journal of Strength & Conditioning Research*, 18(2), 353–358.
- 14 de Ruiter, C. J., van der Linden, R. M., van der Zijden, M. J. a, Hollander, a P., & de Haan, a. (2003). Short-  
15 term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force  
16 rise. *European Journal of Applied Physiology*, 88(4–5), 472–475. [http://doi.org/10.1007/s00421-002-](http://doi.org/10.1007/s00421-002-0723-0)  
17 [0723-0](http://doi.org/10.1007/s00421-002-0723-0)
- 18 Dowse, R. A., McGuigan, M. R., & Harrison, C. (2017). Effects of a Resistance Training Intervention on  
19 Strength, Power, and Performance in Adolescent Dancers. *Journal of Strength and Conditioning*  
20 *Research*.
- 21 Flanagan, E. P., & Comyns, T. M. (2008). The Use of Contact Time and the Reactive Strength Index to  
22 Optimize Fast Stretch-Shortening Cycle Training. *Strength and Conditioning Journal*, 30(5), 32–38.
- 23 Fulford, J., Eston, R. G., Rowlands, A. V., & Davies, R. C. (2015). Assessment of magnetic resonance  
24 techniques to measure muscle damage 24h after eccentric exercise. *Scandinavian Journal of Medicine and*  
25 *Science in Sports*, 25(1), e28–e39. <http://doi.org/10.1111/sms.12234>
- 26 Hayter, K. J., Doma, K., Schumann, M., & Deakin, G. B. (2016). The comparison of cold-water immersion and

- 1 cold air therapy on maximal cycling performance and recovery markers following strength exercises.  
2 *PeerJ*, 4(e1841), 1–17. <http://doi.org/10.7717/peerj.1841>
- 3 Hohenauer, E., Costello, J. T., Stoop, R., Küng, U. M., Clarys, P., Deliens, T., & Clijsen, R. (2018). Cold-water  
4 or partial-body cryotherapy? Comparison of physiological responses and recovery following muscle  
5 damage. *Scandinavian Journal of Medicine and Science in Sports*, 28(3), 1252–1262.  
6 <http://doi.org/10.1111/sms.13014>
- 7 Hopkins, W. G. (2015). Spreadsheets for analysis of controlled trials with adjustment for a predictor.  
8 *Sportscience*. *Sportscience*, (10), 46–50.
- 9 Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in  
10 sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, 41(1), 3–12.  
11 <http://doi.org/10.1249/MSS.0b013e31818cb278>
- 12 Jakeman, J. R., Byrne, C., & Eston, R. G. (2010). Lower limb compression garment improves recovery from  
13 exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology*,  
14 109(6), 1137–1144. <http://doi.org/10.1007/s00421-010-1464-0>
- 15 Jakeman, J. R., Macrae, R., & Eston, R. (2009). A single 10-min bout of cold-water immersion therapy after  
16 strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced  
17 muscle damage. *Ergonomics*, 52(4), 456–460.
- 18 Khan, M. A., Moiz, J. A., Raza, S., Verma, S., Shareef, M. Y., Anwer, S., & Alghadir, A. (2016). Physical and  
19 balance performance following exercise induced muscle damage in male soccer players. *J Phys Ther Sci*,  
20 18(10), 2942–2949. <http://doi.org/10.1589/jpts.28.2942>
- 21 Leeder, J., Gissane, C., van Someren, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and  
22 recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine*, 46(4), 233–240.  
23 <http://doi.org/10.1136/bjsports-2011-090061>
- 24 Leeder, J., van Someren, K., Gaze, D., Jewell, A., Deshmukh, N. I. K., Shah, I., ... Howatson, G. (2014).  
25 Recovery and adaptation from repeated intermittent-sprint exercise. *International Journal of Sports*  
26 *Physiology and Performance*, 9(3), 489–96. <http://doi.org/10.1123/ijsp.2012-0316>

- 1 Machado, A. F., Ferreira, P. H., Micheletti, J. K., de Almeida, A. C., Lemes, Í. R., Vanderlei, F. M., ... Pastre,  
2 C. M. (2016). Can water temperature and immersion time influence the effect of cold water immersion on  
3 muscle soreness? A systematic review and meta-analysis. *Sports Medicine*, 46(4), 503–514.  
4 <http://doi.org/10.1007/s40279-015-0431-7>
- 5 Maffiuletti, N. A., Aagaard, · Per, Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force  
6 development: physiological and methodological considerations. *European Journal of Applied Physiology*,  
7 1–26. <http://doi.org/10.1007/s00421-016-3346-6>
- 8 Mawhinney, C., Low, D. A., Jones, H., Green, D. J., Costello, J. T., & Gregson, W. (2017). Water Mediates  
9 Greater Reductions in Limb Blood Flow than Whole Body Cryotherapy. *Medicine & Science in Sports &  
10 Exercise*. <http://doi.org/10.1249/MSS.0000000000001223>
- 11 McClung, M., & Collins, D. (2007). “Because I know it will!”: placebo effects of an ergogenic aid on athletic  
12 performance. *Journal of Sport and Exercise Psychology*, 29(3), 382–394.
- 13 McLeay, Y., Barnes, M. J., Mundel, T., Hurst, S. M., Hurst, R. D., & Stannard, S. R. (2012). Effect of New  
14 Zealand blueberry consumption on recovery from eccentric exercise-induced muscle damage. *Journal of  
15 the International Society of Sports Nutrition*, 9(1), 19. <http://doi.org/10.1186/1550-2783-9-19>
- 16 Minett, G. M., & Costello, J. T. (2015). Specificity and context in post-exercise recovery: it is not a one-size-  
17 fits-all approach. *Frontiers in Physiology*, 6(April), 1–3. <http://doi.org/10.3389/fphys.2015.00130>
- 18 Nevill, A., & Lane, A. (2007). Why self-report “Likert” scale data should not be log-transformed. *Journal of  
19 Sports Sciences*, 25(1), 1–2. <http://doi.org/10.1080/02640410601111183>
- 20 Norton, L. E., & Layman, D. K. (2006). Leucine regulates translation initiation of protein synthesis in skeletal  
21 muscle after exercise. *The Journal of Nutrition*, 136(2), 533S–537S.
- 22 Peñailillo, L., Blazevich, A., Numazawa, H., & Nosaka, K. (2015). Rate of force development as a measure of  
23 muscle damage. *Scandinavian Journal of Medicine & Science in Sports*, 25(3), 417–427.  
24 <http://doi.org/10.1111/sms.12241>
- 25 Roberts, L. A., Nosaka, K., Coombes, J. S., & Peake, J. M. (2015). Cold water immersion enhances recovery of  
26 submaximal muscle function following resistance exercise. *American Journal of Physiology. Regulatory*,



- 1        *Integrative and Comparative Physiology*, (July 2015), ajpregu.00180.2014-.
- 2        <http://doi.org/10.1152/ajpregu.00180.2014>
- 3        Roberts, L. A., Raastad, T., Markworth, J. F., Figueiredo, V. C., Egner, I. M., Shield, A., ... Peake, J. M. (2015).  
4        Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in  
5        muscle to strength training. *Journal of Physiology*, 593(18), 4285–4301. <http://doi.org/10.1113/JP270570>
- 6        Savic, M., Fonda, B., & Sarabon, N. (2013). Actual temperature during and thermal response after whole-body  
7        cryotherapy in cryo-cabin. *Journal of Thermal Biology*, 38(4), 186–191.  
8        <http://doi.org/10.1016/j.jtherbio.2013.02.004>
- 9        Selfe, J., Alexander, J., Costello, J. T., May, K., Garratt, N., Atkins, S., ... Richards, J. (2014). The effect of  
10        three different (-135°C) whole body cryotherapy exposure durations on elite rugby league players. *PLoS*  
11        *One*, 9(1), e86420. <http://doi.org/10.1371/journal.pone.0086420>
- 12        Tee, J., Bosch, A., & Lambert, M. (2007). Metabolic Consequences of Exercise-Induced Muscle Damage.  
13        *Sports Medicine*, 37(10), 827–836.
- 14        Tipton, M. J., Collier, N., Massey, H., Corbett, J., & Harper, M. (2017). Cold water immersion: kill or cure?  
15        *Experimental Physiology*, 102(11), 1335–1355. <http://doi.org/10.1113/EP086283>
- 16        Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on the signs and symptoms of  
17        delayed onset muscle soreness. *European Journal of Applied Physiology*, 102, 447–455.  
18        <http://doi.org/10.1007/s00421-007-0605-6>
- 19        Vaile, J. M., Gill, N. D., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptoms of delayed  
20        onset muscle soreness. *The Journal of Strength & Conditioning Research*, 21(3), 697–702.
- 21        Wathen, D. (1994). Load assignment. In T. R. Baechle (Ed.), *Essentials of strength training and conditioning*  
22        (pp. 435–446). Champaign, IL: Human Kinetics.
- 23        White, G. G. E., Rhind, S. S. G., & Wells, G. G. D. (2014). The effect of various cold-water immersion  
24        protocols on exercise-induced inflammatory response and functional recovery from high-intensity sprint  
25        exercise. *European Journal of Applied Physiology*. <http://doi.org/10.1007/s00421-014-2954-2>
- 26        Wilson, L. J., Cockburn, E., Paice, K., Sinclair, S., Faki, T., Hills, F. A., ... Dimitriou, L. (2018). Recovery

1 following a marathon: a comparison of cold water immersion, whole body cryotherapy and a placebo  
2 control. *European Journal of Applied Physiology*, 118(1), 153–163. <http://doi.org/10.1007/s00421-017->  
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Table 1. Participant characteristics

	<i>n</i>	Age (y)	Height (m)	Mass (kg)	Predicted 1RM (kg)	Lean mass (kg)	1RM/Lean mass	sRPE
PL	8	25.88 ± 5.19	1.80 ± 0.04	84.88 ± 13.81	125 ± 19.6	63.83 ± 7.51	1.95 ± 0.15	7.50 ± 1.41
CWI	8	21.88 ± 3.40	1.79 ± 0.05	84.39 ± 14.22	126 ± 21.3	66.56 ± 6.29	1.89 ± 0.22	7.63 ± 1.41
WBC	8	26.50 ± 8.40	1.71 ± 0.06	70.92 ± 10.20	120 ± 46.1	58.44 ± 6.49	2.04 ± 0.69	7.50 ± 1.07

Values are presented as mean  $\pm$  SD

1RM, 1 Repetition Maximum; sRPE, session rate of perceived exertion

Table 2. Change over time and group comparisons for perceptual markers

		<b>Changes</b>				<b>Effects</b>	
		Mean; $\pm$ CL		Mean <sup>a</sup> ; $\pm$ CL <sup>b</sup>		Qualitative Outcome	
		Qualitative outcome					
		Placebo	CWI	WBC	PL/CWI	PL/WBC	CWI/WBC
DALDA	B – 24h	0.38; $\pm$ 3.3 Very large $\uparrow^*$	1.5; $\pm$ 0.9 Large $\uparrow^{**}$	-0.38; $\pm$ 0.9 Trivial <sup>**</sup>	1.12; $\pm$ 3.4 Small $\uparrow^*$	-0.76; $\pm$ 3.4 Unclear	-1.88; $\pm$ 1.2 Moderate $\downarrow^{**}$
	B – 48h	-0.25; $\pm$ 2.4 Unclear	1.63; $\pm$ 1.1 Large $\uparrow^{**}$	0.5; $\pm$ 2.5 Small $\uparrow^*$	1.88; $\pm$ 2.6 Moderate $\uparrow^*$	0.75; $\pm$ 3.2 Small $\uparrow^*$	-1.13; $\pm$ 2.6 Unclear
	B – 72h	-1.13; $\pm$ 2.8 Unclear	0.13; $\pm$ 0.2 Trivial <sup>****</sup>	-0.75; $\pm$ 1.7 Unclear	1.26; $\pm$ 2.8 Small $\uparrow^*$	0.38; $\pm$ 3.1 Trivial <sup>*</sup>	-0.88; $\pm$ 1.7 Unclear
DOMS	B – 24h	3.88; $\pm$ 1.4 Very large $\uparrow^{****}$	3.75; $\pm$ 1.4 Very large $\uparrow^{****}$	0.63; $\pm$ 2.1 Small $\uparrow^*$	-0.13; $\pm$ 1.8 Trivial <sup>*</sup>	-3.25; $\pm$ 2.4 Large $\downarrow^{**}$	-3.12; $\pm$ 2.1 Large $\downarrow^{**}$
	B – 48h	3.50; $\pm$ 1.4 Very large $\uparrow^{***}$	4.00; $\pm$ 1.8 Very large $\uparrow^{***}$	0.88; $\pm$ 2.4 Small $\uparrow^*$	0.50; $\pm$ 2.1 Trivial <sup>*</sup>	-2.62; $\pm$ 2.6 Unclear	-3.12; $\pm$ 2.8 Unclear
	B – 72h	1.63; $\pm$ 1.1 Large $\uparrow^{**}$	1.63; $\pm$ 1.6 Large $\uparrow^{**}$	-0.25; $\pm$ 2.0 Trivial <sup>*</sup>	0; $\pm$ 1.8 Trivial <sup>*</sup>	-1.88; $\pm$ 2.2 Unclear	-1.88; $\pm$ 2.4 Unclear

CL, confidence limit. Qualitative outcome represents the likelihood that the true value will have the observed magnitude represented by the number of asterisks (\*) with \*possibly, \*\*likely, \*\*\*very likely and \*\*\*\* most likely.

<sup>a</sup>Mean represents the second named group minus the first named group.

<sup>b</sup>90%CL – add and subtract this number to the mean to obtain the 90% confidence limits for the true difference

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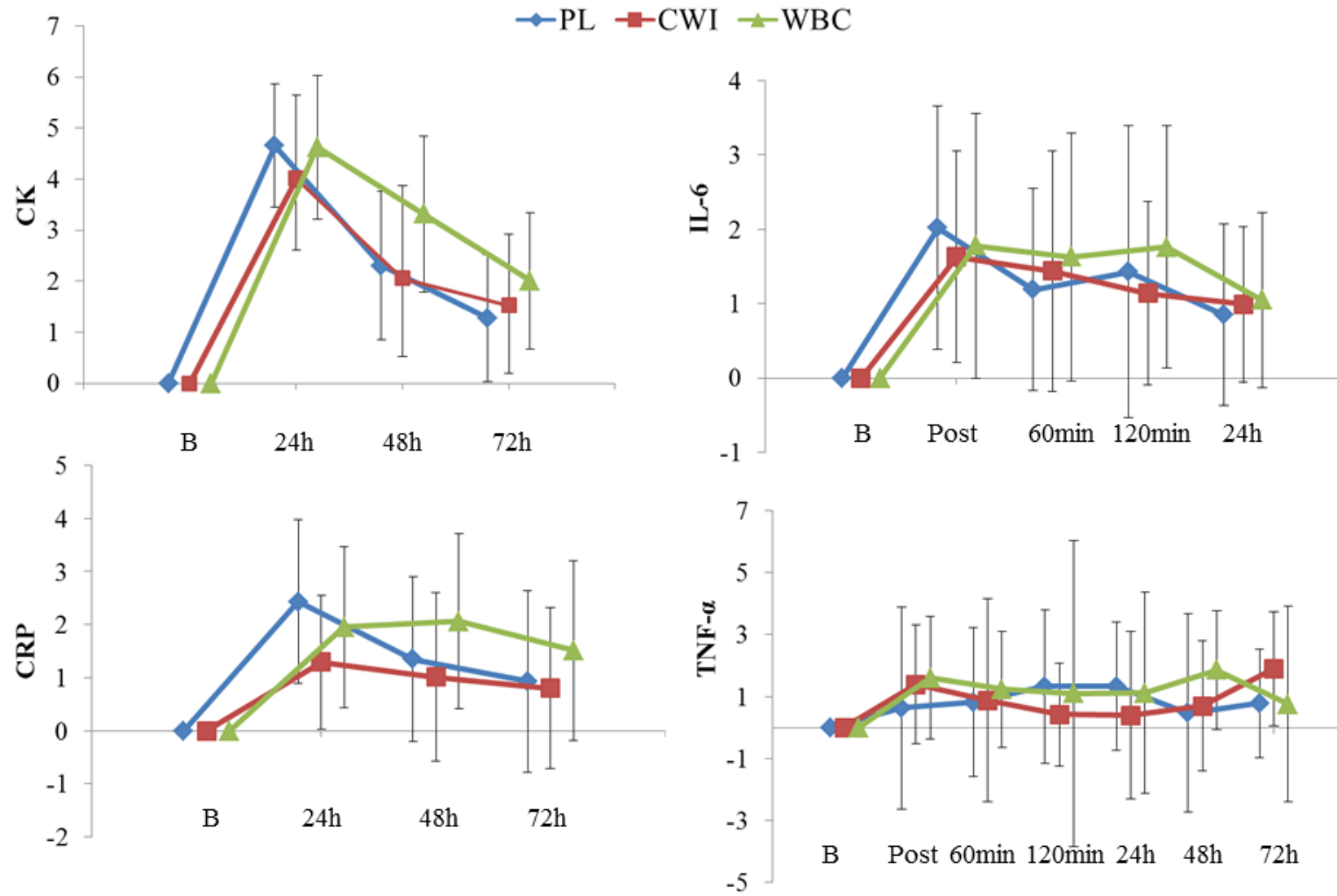


Figure 1. Factor change in blood variables with 90% CL error bars.