Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001591

Title: Can cold water immersion enhance recovery in elite Olympic weightlifters? An individualized perspective

Submission Type: Original investigation

Authors:

Jan Schimpchen[1]

Maximilian Wagner[1]

Alexander Ferrauti[2]

Michael Kellmann[2, 3]

Mark Pfeiffer[4]

Tim Meyer[1]

Institutions:

[1] Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany

[2] Faculty of Sport Science, Ruhr University, Bochum, Germany

[3] School of Human Movement and Nutrition Sciences, The University of Queensland, Brisbane, Australia

[4] Institute of Sports Science, Johannes-Gutenberg University, Mainz, Germany

Corresponding Author: Jan Schimpchen

Institute of Sports and Preventive Medicine, Building B 8.2

Saarland University

66123 Saarbrücken

Germany

Email: jan.schimpchen@uni-saarland.de

Phone: +49 681 30270413

Fax: +49 681 3024296

Running Head: Cold water immersion for elite power athletes

Funding: The present study was funded by the German Federal Institute of Sport Science (REGman: Optimization of Training and Competition: Management of Regeneration in Elite Sports; IIA1-081901/12-16). The authors declare no conflicts of interest.

Abstract

We investigated whether cold water immersion following intensive training sessions can enhance recovery in elite Olympic weightlifters, taking into account each athlete's individual response pattern. The entire German male Olympic weightlifting national team participated in the study (n=7), ensuring collection of data from elite athletes only. Using a randomized cross-over design, the athletes went through two high intensity training microcycles consisting of five training sessions that were either followed by a cold water immersion or passive recovery. Barbell speed in a snatch pull movement, blood parameters as well as subjective ratings of general fatigue and recovery were assessed throughout the study. Physical performance at two snatch pull intensities (85% 1RM: -0.15% vs. -0.22%, P=0.94; 90% 1RM: -0.7% vs. +1.23%, P=0.25) did not differ significantly (condition x time). While questionnaires revealed a significant decline in ratings of overall recovery (P<0.001) and a significantly higher rating of overall stress (P=0.03) over time, no significant differences between conditions (P=0.14; P=0.98) could be revealed. Similarly, neither of the analyzed blood parameters changed significantly between conditions over time (CK: P=0.53; Urea: P=0.43; Cortisol: P=0.59; Testosterone: P=0.53; Testosterone:Cortisol ratio: P=0.69). In general, CWI did not prove to be an effective tool to enhance recovery in elite Olympic weightlifters over a three day intensive training period. However, even though the group was rather homogeneous with regard to performance, there were considerable inter-subject differences in their response to CWI. It appears that athletes are best advised on a case-by-case basis.

Keywords

fatigue; performance; power athletes; resistance training

INTRODUCTION

It is paramount to achieve an adequate balance between training and competition induced stresses and recovery in order to maximize performance levels in elite athletes (1). Specifically athletes that are training and/or competing multiple times per day often experience excessive amounts of stress that might result in temporary impairments in performance due to a variety of factors. Consequently, there is an increased interest among researchers and practitioners to identify adequate modalities to support fast recovery between intensive exposure periods (25).

The use of cold water immersion (CWI) is one of the more popular methods in elite sports_ENREF_3. It is rather low-cost, easily applicable under various circumstances and widely perceived to be performance enhancing. While the underlying physiological and biochemical mechanisms for its proposed effectiveness remain at least partly unclear (2) and are still under investigation (15), a number of studies have shown potentially beneficial impacts on recovery. Vaile, Halson, Gill and Dawson (32) showed that CWI was significantly better at restoring squat jump performance in the three days following a strength training session compared to a passive recovery control condition. Additionally, a recent meta-analysis demonstrated that CWI can be an effective strategy to reduce delayed onset muscle soreness (DOMS) (21). Halson (10) showed that athletes involved in weight-bearing sports might benefit more from cooling than athletes involved in non-weight-bearing sports, while Leeder, Gissane, van Someren, Gregson and

Howatson (20) found positive effects for muscle power, but not for muscle strength. Furthermore, it was suggested by Poppendieck, Faude, Wegmann and Meyer (25) that cooling might have an effect on neuromuscular coordination. These findings seem to suggest that athletes involved in sports that require these particular physical qualities might potentially benefit the most from the use of CWI as a recovery intervention.

However, results of other studies question the proposed effectiveness of CWI as a recovery tool (3, 6, 31). This makes it increasingly difficult for practitioners to decide whether CWI is a worthwhile implementation into the training or competition routine of their respective athletes. Part of that inconclusiveness might stem from the fact that the vast majority of research on the topic focuses on the group mean efficacy of CWI as the intervention, even though research on elite athletes is naturally limited to small sample sizes and therefore often inadequate to result in conclusions that can be generalized for other populations. Indeed, individuals show a wide range of different responses to the same intervention (11, 18, 22). Hence, it appears that specifically in the area of high performance sport individual responses to a given stimulus need to be accounted for in order to be able to provide specific recommendations tailored to each athlete's individual response patterns.

Overall, current literature available on the topic seems to suggest that specifically athletes involved in weight-bearing exercises that require high levels of muscular power and intramuscular coordination could benefit from incorporating CWI as a recovery tool. Also, special consideration needs to be attributed towards inter-individual variability in the observed response to a given stimulus in order to derive individualized athlete recommendations. Consequently, the aim of this study was to investigate whether CWI following intensive training sessions can be a useful recovery tool for elite Olympic weightlifters using an individualized approach.

METHODS

Experimental Approach to the Problem

The study employed a randomized cross-over design consisting of two four-day phases separated by a ten-day wash-out period (Figure 1). Both phases were completed in familiar facilities using standard equipment and followed a high-intensity, Olympic weightlifting specific training protocol as outlined by the German national coach. The athletes mainly performed the competition lifts as well as a number of accessory movements (e.g. back squat, front squat, high pull, push jerk, etc.). In total, the athletes completed about 18-25 working sets per session, generally working in the 3-5 repetition range without going to concentric muscle failure. While exercise selection varied to a certain extent between phases, volume and intensity remained constant.

< insert Figure 1 about here >

Subjects

Seven male members (25 ± 4 y; mean ± SD) of the German national team in Olympic weightlifting volunteered and provided written consent to participate in the study. All athletes were healthy and free of injury throughout data collection and trained to compete in different bodyweight categories (69 kg (n=1), 77 kg (n=2), 85 kg (n=1), 94 kg (n=1), 105 kg (n=2)) according to the classification of the International Weightlifting Federation (IWF). The study was approved by the local Ethics Committee (Ärztekammer des Saarlandes, Saarbrücken, Germany) and conformed to the Declaration of Helsinki.

Procedures

In both phases, athletes underwent a total of five training sessions. Two training sessions were performed on day 1, one session on day 2, and two sessions on day 3. When two training sessions were scheduled for the same day one session took place in the morning (9.30 – 11 a.m.) and one in the afternoon (3.30 – 5 p.m.). The lone training session on day 2 took place in the afternoon (3.30 – 5 p.m.). Each session was immediately followed by either a cold water immersion protocol (CWI) or a control condition (CON). CWI consisted of a single bout of 10 consecutive minutes, during which the athletes were seated and immersed up to their neck in water at between 12°-15°C (25), while CON consisted of 10 min of passive recovery in the same body position. Subsequently, training session intensity was assessed via a rating of perceived exertion (RPE). This method has been considered a good indicator of general internal load (16). Scores were collected using a modified 10 point BORG scale (23).

A sport-specific performance test was carried out at the same time of day on the first and last day of both phases. The test consisted of a snatch pull movement at 85% and 90% of each athlete's individual snatch target weight for the World Championships that would take place 3 months after completion of the study. Maximal barbell velocity (v_{max}) during the pull was recorded using a camcorder (Panasonic GS 500, Panasonic Corporation, Kadoma, Japan) and a specific software package (Realanalyzer, IAT Leipzig, Germany). The test was chosen since the athletes were very familiar with its execution due to a frequent incorporation into their training routine and since v_{max} has previously been shown to be a relevant performance indicator (4).

Venous blood samples were collected from the fasted athletes into 7.5 ml serum vacutainers (Sarstedt AG & Co, Nürnbrecht, Germany) on the mornings of the first, second, and fourth day of both phases. The vacutainers were left to clot at room temperature before being spun in a centrifuge (Hettich EBA 20, Hettich Lab Technology, Tuttlingen, Germany) at 6000 rpm for 10 min. Subsequently, the serum was aliquoted and stored at -18°C.

The samples were analyzed in a certified diagnostic laboratory with regards to concentrations of creatinkinase (CK), urea (UniCel® DxC 600, Beckman Coulter GmbH, Krefeld, Germany), cortisol (Access® 2, Beckman Coulter GmbH, Krefeld, Germany), and free testosterone (ELISA, LDN Labor Diagnostika Nord, Nordhorn, Germany).

Throughout data collection subjective ratings were assessed using the recently developed Acute Recovery and Stress Scale (ARSS)(12). The ARSS consists of 32 adjectives describing physical, emotional, mental, and overall aspects of recovery and stress, which are assessed with a seven-point Likert-type scale ranging from 0 (does not apply at all) to 6 (fully applies). Finally, all the adjectives are subdivided into the following dimensions: physical performance capability, mental performance capability, emotional balance, overall recovery, muscular stress, lack of activation, negative emotional state, and overall stress. The ARSS has been checked for psychometric reliability and validity (12, 19). The athletes were asked to fill in the questionnaire every morning at the same time (paper-based).

Statistical Analyses

Statistical analyses were conducted using STATISTICA 8.0 (StatSoft Inc., Tulsa, AZ, USA) and Microsoft Excel™. Results are reported as means ± standard deviation (SD) unless otherwise stated. Distribution of all data was checked using a Kolmogorov-Smirnov normality test. For normally distributed data a two-way repeated measures ANOVA was used to assess changes in the interaction between condition (CON vs CWI) and time. The same statistical test was used for the analysis of the ARSS. The authors are aware that parametric tests are generally not adequate for ordinal data. After a thorough review of current literature on the topic, we decided to follow recommendations given by Sullivan and Artino (30) to employ parametric procedures. An α-level of $P<0.05$ was accepted as statistically significant.

Furthermore, inter-condition differences ± 90% confidence limits (CL) as well as inter-condition differences expressed as Cohen's d effect sizes (ES) ± 90% CL are reported to compare the magnitude of the difference (thresholds: 0.2 – trivial; 0.6 – small; 1.2 – moderate; 2.0 – large; 4.0 – extremely large). Magnitude based inferences were conducted in order to determine the smallest worthwhile difference between conditions (14) using a published spreadsheet (13). This approach represents a contemporary method of data analysis that uses confidence limits in order to calculate the probability that a difference is practically meaningful. For all parameters a between-subject SD of 0.2 (small effect) was considered to be meaningful. This allows for a quantitative assessment of the chance for the true value to be positive, trivial, and negative as well as for an assignment of qualitative probabilistic terms using the following scale: <0.5% - *most unlikely, almost certainly not*; 0.5–5% - *very unlikely*; 5–25% - *unlikely, probably not*; 25-75% - *possibly*; 75-95% - *likely, probably*; 95-99.5% - *very likely*; >99.5% - *most likely, almost certainly* (14). In case chances for both negative and positive effects were calculated to be >5%, results were deemed *unclear* (14).

RESULTS

Five intensive training sessions on three consecutive days induced a strong subjective sense of fatigue in the athletes in both conditions. Questionnaires revealed a significant decline in ratings of overall recovery (P<0.001) and a significantly higher rating of overall stress (P=0.033) over time. Similarly, the analysis of blood borne markers revealed a significant increase of CK (P<0.001) and significantly lower values of cortisol (P=0.002) over the duration of the training phases.

On a group level, there were no significant interaction (condition x time) effects across all parameters (Tables 1 & 2), including RPE (P=0.447). Magnitude based inferences showed CWI to possibly have a trivial negative effect on physical performance in one of the sport-specific performance tests (Table 2) while also showing it is likely to initially result in a small increase in cortisol levels (Table 2). Questionnaires revealed that CWI did not significantly change the athletes' perception of recovery and fatigue in any of the eight dimensions. Conducting magnitude based inferences revealed that the athletes' subjective feeling of overall recovery was very likely positively influenced by the cold water intervention while CWI also very likely affected the athletes' emotional state in a negative way, especially towards the end of the training microcycle (Table 2).

< insert Table 1 and Table 2 about here >

On an individual level, athletes showed differing responses to the intervention (Figures 2 & 3). One athlete (#5) improved performance in both tests throughout the intervention condition (85%: +1.1%; 90%: +2.9%), but saw a decline in performance for both tests during the control condition (85%: -6.7%; 90%: -1.7%). For this particular case questionnaires also revealed an improved feeling of overall recovery and less overall stress for CWI in comparison to CON. On the other end of the spectrum, two athletes (#3 & #4) performed consistently worse during CWI (#3: 85%: -2.5%; 90%: -0.5% / #4: 85%: -2.9%; 90%: -4.5%) and better or the same during CON

(#3: 85%: +2.6%; 90%: +2.7% / #4: 85%: +1.5%; 90%: ±0%) while questionnaires showed no or only slight differences in subjective feeling of recovery.

< insert Figure 2 and Figure 3 about here >

DISCUSSION

To the authors' knowledge, this study is the first to investigate the effectiveness of CWI as a recovery tool for elite Olympic weightlifters. In fact, the training history and experience of the participants is a unique aspect for any study investigating the effects of a recovery intervention on the physical qualities in this particular cohort. Previous reviews and meta-analyses have found CWI to be effective in terms of performance restoration for athletes involved in weight-bearing sports (10) that require high levels of muscular power (20) and neuromuscular coordination (25). Since Olympic weightlifting is largely based on these physical qualities (28, 29) it is within reason to speculate CWI to be a suitable recovery tool for this particular sport. However, results of the present study question the aforementioned assumptions. The application of CWI after five high-intensity training sessions over three consecutive days did not prove to be a successful tool to enhance overall performance capabilities in seven elite German Olympic weightlifters.

The results of the current study are in line with previous research investigating the effectiveness of CWI on strength measures following resistance type exercise in non-elite populations. Pointon, Duffield, Cannon and Marino (24) found that a single application of CWI does not significantly enhance restoration in muscle function and contractile damage following high-intensity eccentric exercise. Similarly, Jakeman, Macrae and Eston (17) showed that a single bout of CWI after plyometric activity did not provide beneficial effects to alleviate the symptoms of EIMD nor did it enhance counter movement jump performance or maximal voluntary contraction of the quadriceps. These results are confirmed by further studies using similar approaches (7, 9, 27, 31).

Positive effects of CWI on the restoration of performance parameters have been found in a study carried out by Vaile, Halson, Gill and Dawson (32), which investigated the effects of CWI on a dynamic power measure (squat jump) in 12 non-elite, resistance trained males after a DOMS-inducing strength training session. It was shown that CWI was significantly better at restoring squat jump performance in the three days following the training session compared to a passive recovery control condition. While the measure of dynamic power employed in the current study is not limited to lower limb power exclusively, the squat jump as a performance measure is rather similar to the snatch pull in terms of the underlying movement pattern. It is therefore worth noting that CWI was shown to be a potentially good recovery method for power-dependent movements.

The intensive nature of five training sessions provided an acutely fatiguing stimulus to the athletes. Whilst performance capabilities remained rather consistent after three days of training, increased markers of muscle damage as well as decreased subjective ratings of recovery indicated that athletes were objectively and subjectively fatigued. Results showed that the athletes' perception of overall recovery was very likely enhanced in the CWI condition. This finding is not particularly surprising, given that prior research has found CWI to be an effective strategy to reduce DOMS and thereby enhance the perception of recovery (5, 20). These subjective responses are rather common for interventions that cannot easily be blinded. Indeed, it has been shown that the placebo effect might potentially account for most of these effects (3). It is therefore important to point out that an athlete's belief in a certain recovery protocol might play an integral part in the subsequent subjective response to the treatment. Coaches and sport scientists should acknowledge this fact and specifically devote time to stress the importance of recovery to the long-term development of performance, thereby potentially increasing the athletes' responsiveness to a certain treatment.

Subjective ratings also revealed that CWI very likely affected the athletes' emotional state in a negative way. This is particularly important in situations where CWI is used rather regularly. A negative mindset going into a training session due to an imminent immersion into cold water may lower the quality of subsequent training performance. The coaching staff should try to remain aware of the emotional state of the athletes and assess individually whether CWI is suitable as a recovery method or is rather perceived as an additional stressor.

Apart from a negative subjective responsiveness, further evidence has emerged that objectively questions the efficacy of CWI as a chronic recovery tool for resistance-type exercise. Fröhlich, Faude, Klein, Pieter, Emrich and Meyer (8) analyzed the effects of a regular application of CWI on adaptations to strength training over a five-week training cycle in 17 male sport students. They found that measures of muscular strength were reduced by 1-2% for the cooling condition compared to an uncooled control condition. These results were confirmed by Roberts, Raastad, Markworth, Figueiredo, Egner, Shield, Cameron-Smith, Coombes and Peake (26), who showed that a long-term application of CWI can attenuate functional, morphological and molecular adaptations to strength training. These changes may translate to a reduction of long-term training gains in muscle strength and hypertrophy. Overall, it appears that the use of CWI should be planned strategically in order to enhance recovery without jeopardizing muscular adaptations. Based on the current data, CWI after 5 consecutive training sessions did not negatively affect performance capabilities in the athletes.

When assessing individual response patterns, it was shown that one athlete (#5) seemed to acutely benefit from the application of CWI. Measures of performance as well as of subjective rating of well-being improved during CWI compared to CON. For this particular athlete it might be important to further stress the positive connotation of CWI in order to reinforce his belief in the effectiveness of the intervention. This might be specifically helpful in phases immediately prior to competition when the reduction of fatigue is prioritized over further adaptive processes. On the other hand, two athletes (#3 & #4) reacted acutely negative to the intervention. A drop-off in performance along with an increased feeling of negativity clearly demonstrate that this particular recovery protocol was unable to alleviate training-induced symptoms of fatigue. Based on the current findings, these two athletes should be advised against the use of CWI and could potentially be more receptive to other recovery interventions. The validity of these particular recommendations could be further supported if subsequent investigations found these effects to be individually reproducible. This would allow for a more informed decision-making process regarding future application of CWI on an individual level.

Overall, a prevailing lack of scientific studies investigating recovery interventions in elite athletes involved in strength and power-type disciplines makes it hard to further discuss the results of the present study, which only recruited elite level Olympic weightlifters. The systemic recovery from (near) maximal muscular effort is a topic that has attracted less academic interest compared to other areas, i.e. endurance-type activity. Future research should be directed towards this cohort, even though access to elite athletes in this area can potentially be difficult.

The authors acknowledge limitations to the current study. The two training phases were not completely identical with regard to exercise selection. The athletes were preparing for the World Championships that would take place 3 months upon completion of the study. In order to assure external validity as well as not to interfere with the athletes' preparations, the design of the training sessions remained in the hands of the national coach. Changes in exercise selection reflect the natural progression towards the World Championships as outlined by the coaching staff. However, general training load remained the same. Minor variations in exercise selection should therefore not have systematically affected the current results. Moreover, as is often the case with elite athletes involved in individual sports, a shortage of potential participants made it nearly impossible to increase the sample size. A possible way to improve reporting data from small samples might be to use a more qualitative approach which takes into account individual responses to the intervention. This perspective might add valuable information in the area of high-performance individual sports.

To conclude, this study adds to the growing body of literature questioning the principal efficacy of CWI as a recovery tool (3, 8, 26). For the first time it has been shown that elite Olympic weightlifters on average do not show signs of improved performance recovery from multiple high intensity sport specific training sessions employing a CWI protocol post-workout. This particular population was hypothesized to benefit from the intervention due to the inherent characteristics of the sport that requires qualities previously found to be positively affected by CWI. However, results of the present study could not confirm these findings.

Inter-individual variability in the response to the given stimulus calls for an individualized approach to recovery management (11, 22). Recent research has demonstrated the need to qualitatively assess each athlete individually in order to be able to to provide specific recommendations tailored to each athlete's own response patterns. This is particularly true for elite populations and needs to be accounted for by sport scientists and coaches in order to maximize their athletes' long-term performance development.

PRACTICAL APPLICATIONS

Elite Olympic weightlifters should be advised on a case-by-case basis whether the application of CWI can be a useful implementation into their training or competition routines. Inter-individual differences in the response to the treatment do not allow for a more general practical recommendation. If CWI is employed, coaches and sport scientists are advised to cautiously monitor the subjective well-being of their athletes since CWI was shown to very likely have a negative effect on the athletes’ emotional state.

ACKNOWLEDGEMENTS

The present study was funded by the German Federal Institute of Sport Science (REGman: Optimization of Training and Competition: Management of Regeneration in Elite Sports; IIA1-081901/12-16). The authors declare no conflicts of interest. The authors deeply appreciate the time and participation given by the athletes. Many thanks are also directed to the coaching staff for their assistance and enthusiasm towards the project.

References

1. Barnett A. Using recovery modalities between training sessions in elite athletes: does it help? *Sports Med* 36: 781-796, 2006.
2. Bleakley CM and Davison GW. What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *Br J Sports Med* 44: 179-187, 2010.
3. Broatch JR, Petersen A, and Bishop DJ. Postexercise cold water immersion benefits are not greater than the placebo effect. *Med Sci Sports Exerc* 46: 2139-2147, 2014.
4. Campos J, Poletaev P, Cuesta A, Pablos C, and Carratala V. Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *J Strength Cond Res* 20: 843-850, 2006.
5. Cheung K, Hume P, and Maxwell L. Delayed onset muscle soreness : treatment strategies and performance factors. *Sports Med* 33: 145-164, 2003.
6. Crowe MJ, O'Connor D, and Rudd D. Cold water recovery reduces anaerobic performance. *Int J Sports Med* 28: 994-998, 2007.
7. Eston R and Peters D. Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *J Sports Sci* 17: 231-238, 1999.
8. Fröhlich M, Faude O, Klein M, Pieter A, Emrich E, and Meyer T. Strength training adaptations after cold-water immersion. *J Strength Cond Res* 28: 2628-2633, 2014.
9. Goodall S and Howatson G. The effects of multiple cold water immersions on indices of muscle damage. *J Sports Sci Med* 7: 235-241, 2008.
10. Halson SL. Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery? *Int J Sports Physiol Perform* 6: 147-159, 2011.
11. Hecksteden A, Kraushaar J, Scharhag-Rosenberger F, Theisen D, Senn S, and Meyer T. Individual response to exercise training - a statistical perspective. *J Appl Physiol* 118: 1450-1459, 2015.
12. Hitzschke B, Holst T, Ferrauti A, Meyer T, Pfeiffer M, and Kellmann M. Entwicklung des Akutmaßes zur Erfassung von Erholung und Beanspruchung im Sport [Development of the Acute Recovery and Stress Scale] *Diagnostica*: in press, 2016.
13. Hopkins WG. A spreadsheet for fully controlled crossovers. *Sportscience* 9, 2005.
14. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
15. Ihsan M, Watson G, and Abbiss CR. What are the Physiological Mechanisms for Post-Exercise Cold Water Immersion in the Recovery from Prolonged Endurance and Intermittent Exercise? *Sports Med*: in press, 2016.
16. Impellizzeri FM, Borg E, and Coutts AJ. Intersubjective comparisons are possible with an accurate use of the Borg CR scales. *Int J Sports Physiol Perform* 6: 2-4; author reply 4-5, 2011.
17. Jakeman JR, Macrae R, and Eston R. A single 10-min bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics* 52: 456-460, 2009.
18. Julian R, Meyer T, Fullagar HH, Skorski S, Pfeiffer M, Kellmann M, Ferrauti A, and Hecksteden A. Individual patterns in blood-borne indicators of fatigue - trait or chance. *J Strength Cond Res*: in press, 2016.
19. Kölling S, Hitzschke B, Holst T, Ferrauti A, Meyer T, Pfeiffer M, and Kellmann M. Validity of the Acute Recovery and Stress Scale – Training Monitoring of the German Junior National Field Hockey Team. *International Journal of Sports Science & Coaching* 10: 529-542, 2015.

20. Leeder J, Gissane C, van Someren K, Gregson W, and Howatson G. Cold water immersion and recovery from strenuous exercise: a meta-analysis. *Br J Sports Med* 46: 233-240, 2012.

21. Machado AF, Ferreira PH, Micheletti JK, de Almeida AC, Lemes IR, Vanderlei FM, Netto Junior J, and Pastre CM. Can Water Temperature and Immersion Time Influence the Effect of Cold Water Immersion on Muscle Soreness? A Systematic Review and Meta-Analysis. *Sports Med* 46: 503-514, 2015.

22. Mann TN, Lamberts RP, and Lambert MI. High responders and low responders: factors associated with individual variation in response to standardized training. *Sports Med* 44: 1113-1124, 2014.

23. Noble BJ, Borg GA, Jacobs I, Ceci R, and Kaiser P. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med Sci Sports Exerc* 15: 523-528, 1983.

24. Pointon M, Duffield R, Cannon J, and Marino FE. Cold application for neuromuscular recovery following intense lower-body exercise. *Eur J Appl Physiol* 111: 2977-2986, 2011.

25. Poppendieck W, Faude O, Wegmann M, and Meyer T. Cooling and performance recovery of trained athletes: a meta-analytical review. *Int J Sports Physiol Perform* 8: 227-242, 2013.

26. Roberts LA, Raastad T, Markworth JF, Figueiredo VC, Egner IM, Shield A, Cameron-Smith D, Coombes JS, and Peake JM. Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. *J Physiol* 593: 4285-4301, 2015.

27. Sellwood KL, Brukner P, Williams D, Nicol A, and Hinman R. Ice-water immersion and delayed-onset muscle soreness: a randomised controlled trial. *Br J Sports Med* 41: 392-397, 2007.

28. Storey A and Smith HK. Unique aspects of competitive weightlifting: performance, training and physiology. *Sports Med* 42: 769-790, 2012.

29. Suchomel TJ, Comfort P, and Stone MH. Weightlifting pulling derivatives: rationale for implementation and application. *Sports Med* 45: 823-839, 2015.

30. Sullivan GM and Artino AR, Jr. Analyzing and interpreting data from likert-type scales. *J Grad Med Educ* 5: 541-542, 2013.

31. Takeda M, Sato T, Hasegawa T, Shintaku H, Kato H, Yamaguchi Y, and Radak Z. The effects of cold water immersion after rugby training on muscle power and biochemical markers. *J Sports Sci Med* 13: 616-623, 2014.

32. Vaile J, Halson S, Gill N, and Dawson B. Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness. *Eur J Appl Physiol* 102: 447-455, 2008.

Figure 1. Visualization of the cross-over design employed in this study.

Figure 2. Barbell snatch pull velocity at 85% of the estimated 1 RM for CON (a) and CWI (b). Bars indicate group mean velocity, while lines display individual trends.

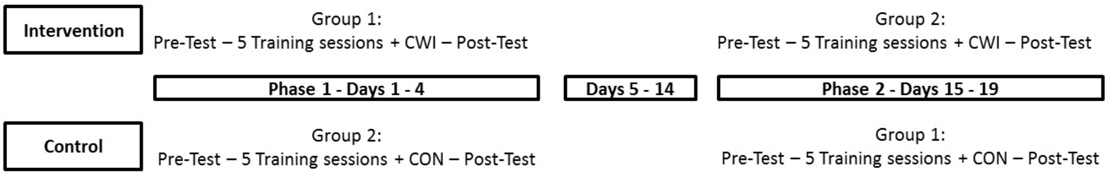
Figure 3. Barbell snatch pull velocity at 90% of the estimated 1 RM for CON (a) and CWI (b). Bars indicate group mean velocity, while lines display individual trends.

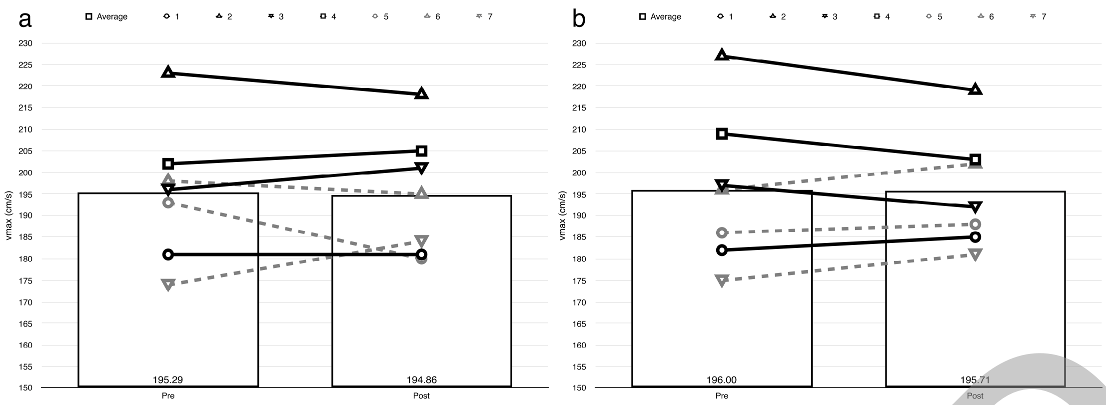
Table 1. Overview of all parameters assessed throughout the study. Results are displayed as mean ± SD.

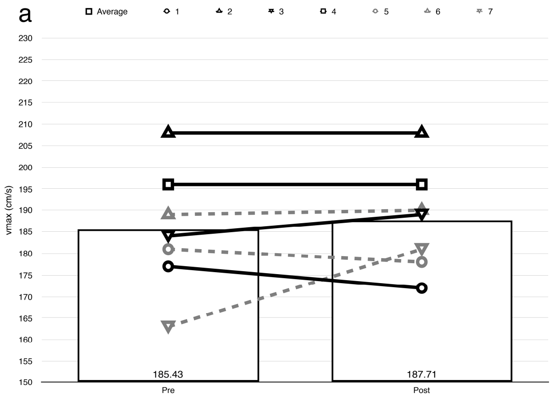
	CON				CWI			
	Day 1 (Pre)	Day 2	Day 3	Day 4 (Post)	Day 1 (Pre)	Day 2	Day 3	Day 4 (Post)
vmax at 85% (cm/s)	195.29 ± 15.72			194.86 ± 14.18	196.00 ± 17.64			195.71 ± 13.16
vmax at 90% (cm/s)	185.43 ± 14.32			187.71 ± 12.07	185.00 ± 21.78			183.71 ± 16.97
CK (U/L)	192.29 ± 58.23	460.43 ± 180.74		542.00 ± 270.85	198.43 ± 75.15	455.43 ± 229.20		582.14 ± 304.95
Urea (mg/dl)	44.14 ± 8.71	46.86 ± 11.01		43.86 ± 12.76	41.57 ± 7.50	46.57 ± 10.00		45.57 ± 7.41
Free Testosterone (pg/ml)	15.62 ± 9.33	15.79 ± 9.86		15.83 ± 9.17	10.98 ± 2.34	17.43 ± 17.04		16.71 ± 11.64
Cortisol (µg/dl)	15.98 ± 1.69	13.48 ± 2.21		13.41 ± 2.72	14.45 ± 3.80	13.80 ± 3.43		12.65 ± 1.16
Free Testosterone/Cortisol Ratio	1.01 ± 0.66	1.26 ± 0.97		1.23 ± 0.74	0.86 ± 0.47	1.39 ± 1.53		1.35 ± 1.05
Physical performance capability	4.14 ± 0.69	3.71 ± 0.49	3.86 ± 0.69	3.14 ± 0.90	4.00 ± 1.00	3.57 ± 0.79	3.43 ± 0.98	3.57 ± 0.79
Mental performance capability	4.71 ± 0.49	4.14 ± 0.38	4.29 ± 0.76	4.14 ± 0.69	4.14 ± 0.90	4.00 ± 1.29	3.86 ± 0.69	3.86 ± 0.38
Emotional balance	5.00 ± 0.00	5.00 ± 0.00	4.71 ± 0.76	4.86 ± 0.38	4.86 ± 0.69	4.71 ± 0.49	4.29 ± 0.76	4.86 ± 0.38
Overall recovery	4.57 ± 0.53	3.86 ± 0.90	3.29 ± 0.76	2.71 ± 1.38	4.57 ± 0.79	3.43 ± 0.53	3.29 ± 0.76	3.57 ± 0.79
Muscular stress	1.57 ± 0.79	2.29 ± 0.95	2.86 ± 1.21	3.29 ± 1.38	1.43 ± 0.79	2.43 ± 1.13	3.29 ± 0.95	3.00 ± 1.00
Lack of activation	1.86 ± 1.21	1.43 ± 0.53	1.57 ± 0.98	2.00 ± 1.15	1.57 ± 1.13	2.29 ± 1.25	1.86 ± 0.69	2.00 ± 0.00
Negative emotional state	0.71 ± 0.76	1.14 ± 0.90	1.14 ± 0.90	0.86 ± 0.38	0.71 ± 0.76	0.57 ± 0.53	1.29 ± 0.49	1.71 ± 1.50
Overall stress	1.57 ± 1.27	2.43 ± 0.98	2.43 ± 0.98	3.14 ± 1.35	1.57 ± 1.27	2.29 ± 1.11	2.57 ± 0.98	3.00 ± 1.00

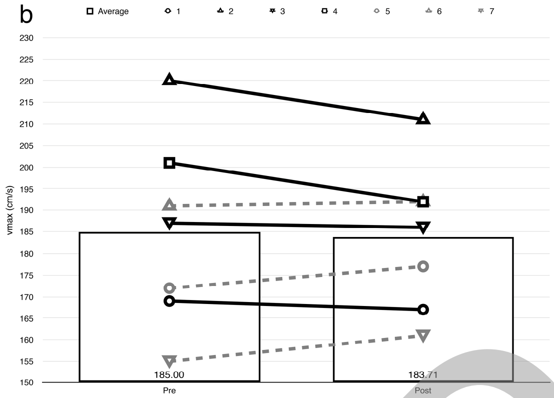
Table 2. Statistical analysis of all parameters. Overall P-value refers to the interaction of condition x time.

	Largest inter-condition difference					Overall P-value
	Difference ± 90% CL	Difference as Cohen ES ± 90% CL	Quantitative chances (%) (positive/trivial/negative)	Qualitative inference	Time Point	
vmax at 85% (cm/s)	0.14 ± 6.84	0.01 ± 0.43	21/60/19	Unclear	Day 4 - Day 1	0.969
vmax at 90% (cm/s)	-3.57 ± 5.41	-0.20 ± 0.31	2/47/50	Possibly negative	Day 4 - Day 1	0.247
CK (U/L)	45.14 ± 79.92	0.70 ± 1.24	77/13/10	Unclear	Day 4 - Day 2	0.529
Urea (mg/dl)	4.29 ± 6.77	0.54 ± 0.85	77/16/7	Unclear	Day 4 - Day 1	0.434
Free Testosterone (pg/ml)	6.28 ± 11.84	0.90 ± 1.70	77/10/13	Unclear	Day 2 - Day 1	0.527
Cortisol (µg/dl)	1.85 ± 2.42	0.63 ± 0.82	83/13/5	Likely positive	Day 2 - Day 1	0.589
Free Testosterone/Cortisol Ratio	0.29 ± 0.68	0.52 ± 1.23	68/17/15	Unclear	Day 2 - Day 1	0.686
Physical performance capability	0.86 ± 0.89	1.03 ± 1.08	91/6/3	Likely positive	Day 4 - Day 3	0.263
Mental performance capability	0.43 ± 1.03	0.57 ± 1.36	69/15/16	Unclear	Day 2 - Day 1	0.851
Emotional balance	0.43 ± 0.58	0.90 ± 1.22	85/9/6	Unclear	Day 4 - Day 3	0.504
Overall recovery	1.29 ± 0.82	1.99 ± 1.26	98/1/1	Very likely positive	Day 4 - Day 2	0.139
Muscular stress	-0.71 ± 0.70	-0.94 ± 0.92	3/6/92	Likely negative	Day 4 - Day 3	0.741
Lack of activation	1.14 ± 1.37	1.00 ± 1.20	88/7/5	Likely positive	Day 2 - Day 1	0.475
Negative emotional state	1.43 ± 1.26	1.97 ± 1.74	95/2/3	Very likely positive	Day 4 - Day 2	0.094
Overall stress	-0.29 ± 1.32	-0.23 ± 1.08	23/24/52	Unclear	Day 4 - Day 3	0.979


Intervention
Group 1:
Pre-Test – 5 Training sessions + CWI – Post-Test
Group 2:
Pre-Test – 5 Training sessions + CWI – Post-Test
Phase 1 - Days 1 - 4
Days 5 - 14
Phase 2 - Days 15 - 19
Control
Group 2:
Pre-Test – 5 Training sessions + CON – Post-Test
Group 1:
Pre-Test – 5 Training sessions + CON – Post-Test


a
Average
1
2
3
4
5
6
7
vmax (cm/s)
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
195.29
194.86
Pre
Post
b
Average
1
2
3
4
5
6
7
vmax (cm/s)
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
196.00
195.71
Pre
Post


a
Average
1
2
3
4
5
6
7
vmax (cm/s)
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
185.43
187.71
Pre
Post


b
Average
1
2
3
4
5
6
7
vmax (cm/s)
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
185.00
183.71
Pre
Post