The physiological effects of daily Cold-water immersion on 5-day tournament performance in international standard youth field-hockey players

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Abstract

PURPOSE: This study examined the effects of daily post-exercise cold-water immersion (CWI) on match performance, perceptual recovery, and biomarkers of muscle damage and metabolic load during a 5-day international tournament of elite youth field-hockey players.

METHODS: The entire German under-18 national squad ($n=18$) were randomly assigned to a daily CWI- (5-min at ~6°C; excluding the head; $n=9$) or passive recovery (CON; $n=9$) intervention. Training- and match-performance was assessed using a GPS-tracking system and perceived exertion (RPE). Daily ratings of delayed onset muscle soreness (DOMS), perceived stress and recovery, quality of sleep, heart-rate recovery (HRR) and serum creatinekinase (CK), lactate-dehydrogenase, and urea nitrogen were also recorded. Repeated sprint ability (RSA) and counter-movement jump (CMJ) was carried out on day 1 and 5.

RESULTS: There was no significant between intervention differences in time on pitch, total distance, velocity-zones and accelerometer-bases parameters during match performance (all $p > 0.05$). DOMS ($p < 0.01$), RPE ($p < 0.01$), and CK ($p < 0.01$) were significantly elevated over the course of the tournament; however, no between intervention effects were observed (all $p > 0.05$). Both groups were able to maintain RSA and CMJ (all $p > 0.05$).

CONCLUSION: In conclusion, daily post-exercise CWI did not improve match performance, perceptual recovery, or biomarkers of muscle damage and metabolic load in elite youth field-hockey players.

Keywords: Recovery, DOMS, GPS-tracking, Elite athletes, Biomarkers

Abbreviations:

ACC	Accelerations
ANOVA	Analysis of variance
BUN	Blood urea nitrogen
CK	Creatinekinase
CMJ	Counter-movement jump
CON	Control
CWI	Cold-water immersion
DEC	Decelerations
DOMS	delayed onset muscle soreness
ExE	Explosive efforts
GPS	Global positioning system
HR_{ex}	Exercise heart rate
HRR	Heart rate recovery
HSD	High-speed distance
LDH	Lactate- dehydrogenase
RPE	Rating of perceived exertion
RSA	Repeated sprint ability
TD	Total distance
T_{skin}	Skin temperature
VZ	Velocity zone

Introduction

In elite international field hockey tournaments, players are required to play and achieve their best performance possible almost daily, with the first 3 matches often scheduled within 4 days (Jennings et al. 2012). Repeating high-intensity exercise with limited time for recovery may lead to accumulated fatigue and consequently, reduced performance capacity (Spencer et al. 2005, Rowsell et al. 2011, Clarkson and Hubal 2002). Reductions in exercise duration and intensity for 1-2 days, following high-intensity exercise as recommended (Cheung et al. 2003), are not always possible due to the tournaments schedule. Therefore, protocols to enhancing recovery or reducing fatigue between matches are an important factor for success and the players' ability to maintain performance throughout the tournament.

The use of time-motion analysis and GPS-tracking devices is widely spread to quantify physical activity in team sports (Lythe and Kilding 2011, White and MacFarlane 2013, White and MacFarlane 2015, Cummins et al. 2013). It has been well demonstrated that decrements in total running distance (TD) and high-speed running distance (HSD) occur throughout team-sport tournaments (e.g. soccer and rugby), potentially indicating accumulated fatigue (Rowsell et al. 2011, Johnston et al. 2013). In elite field hockey, findings are inconsistent as some studies reported reductions in TD, HSD and number of sprints (Spencer et al. 2005, Ihsan et al. 2017), while another stated no changes (Jennings et al. 2012). However, it is well established that there is a large variability in physical match performance in elite teams, which is likely attributed to technical and tactical requirements (Gregson et al. 2010). Thus, players may not be required to reach their physiological limits and decrements in certain recovery parameters are not necessarily associated with accumulated fatigue.

Therefore, various surrogate outcome measures are used to monitor fatigue throughout consecutive training and competition, such as counter-movement jumps (CMJ), repeated sprint ability (RSA) or heart rate recovery tests (HRR) (Rowsell et al. 2009, Buchheit et al. 2013, Thorpe et al. 2015). Moreover, perturbations of various biomarkers related to exercise-induced muscle damage and inflammation are frequently assessed to quantify the athletes load and recovery status during training and competition (Meyer and Meister 2011). Additionally, the players' internal load can be assessed using psychometric questionnaires related to delayed onset muscle soreness (DOMS), freshness, quality of sleep, fatigue and stress (Buchheit et al. 2013, Hitzschke et al. 2015, Williamson and Hoggart 2005). In order to get a better understanding of any potential impact of an recovery-intervention, it has been recommended to use multiple parameters and assessments to quantify performance, fatigue and recovery (Halson 2014, Kellmann et al. 2018).

Post-exercise cooling is a common recovery modality for prevention and treatment of exercise-induced fatigue (Poppendieck et al. 2013, Hohenauer et al. 2015). Among the most common methods are brief exposures to cold water (cold-water immersion, CWI, ~ 5-13°C for 5-20 min), extremely cold air (whole-body cryotherapy, WBC, ~ -110°C for 2 to 4 min) or extremely cold vaporized liquid nitrogen (partial- body cryotherapy, PBC, -110-195°C for 1-3 min) (Bleakley et al. 2012, Costello et al. 2015, Bouzigon et al. 2016, Leeder et al. 2012). Despite its increasing popularity and application in sports, evidence that cryotherapy improves recovery is equivocal (Murray and Cardinale 2015, Poppendieck et al. 2013, Leeder et al. 2012). Several reviews of the literature suggest, that by its primary effects of reducing tissue temperature, peripheral blood flow, and nerve conductance velocity, cryotherapy attenuates the perception of exercise-induced muscle damage and DOMS (Bleakley et al. 2012, Hohenauer et al. 2015, Ihsan et al. 2016). However, concurrent findings are published regarding the effects of cryotherapy on biomarkers of muscle damage and inflammation (Ascensao et al. 2011, Pournot et al. 2011, Ingram et al. 2009, Krueger et al. 2018). These disparate results might be related to differences in methodology, such as cooling temperature, immersion depth, initial exercise modality and time points of recovery parameter assessment. In addition, it has been suggested that CWI is most effective after prolonged whole body endurance and/or intermittent based exercise (Bleakley et al. 2012, Ihsan et al. 2016). However, most studies focused on single exercise bouts and single applications of CWI in recreational trained participants, thus data of daily CWI applications following repetitive high-intensity training and match performance in international level athletes is extremely limited. To our knowledge, no study has investigated the effects of CWI compared to a control condition on 1) match performance and 2) various recovery parameters during a tournament in elite field hockey to date.

Accordingly, the aim of the present study was to investigate the effectiveness of daily post-exercise CWI on physiological and perceptual markers of fatigue and recovery and physical match-performance during a 5-day tournament in international standard youth field-hockey players. We hypothesised that 1) CWI would not improve performance-related parameters or biomarkers of muscle damage or fatigue, and 2) that CWI would improve perceptual markers associated with fatigue and recovery.

Methods

Participants

The under-18 German national Squad in field hockey participated in the present study. The team won the European Championship in the in the year of the present studies conduction. During the investigated tournament the national squad consisted of 18 healthy male field hockey players (mean ± SD: age 16.6 ± 0.6 yrs.; height 182.1 ± 5.5; mass 73.8 ± 7.8 kg). All participants played field hockey for at least five years with three or more training sessions per week and regular league matches in their respective home clubs. Additionally, they were familiar with different recovery methods like message or CWI. Before the tournament, players were informed about the testing procedures and potential risks and familiarized with the questionnaires used during the investigation. After that, all volunteers and their parents or legal guardians gave their written informed consent to participate. The study, including all procedures was conducted in accordance with the Declaration of Helsinki and approved by the ethical committee of the German Sport University Cologne.

Experimental design

An overview of the experimental design is presented in figure 1.

Briefly, the tournament took place immediately after the last week of the regular season with players arriving from their respective home clubs in the morning of day 1. After anthropometric measurements and baseline assessment of questionnaires and biomarkers, the team completed a 15-min warm-up, followed by performance testing of CMJ and 6 x 30m RSA. Afterwards, the players were paired by the coaches according to their playing position, level of experience and anthropometrics. Randomly (coin toss) one player of each pair was assigned to the intervention (CWI) and control (CON) group, respectively. In the afternoon of day 1 a friendly match against a local club was carried out, consisting of 3 x 20 min. On day 2 tactical coaching and a 2 h – training session was conducted. On days 3 – 5, the team participated in an international tournament with one match per day. In the afternoon of day 5 assessment of CMJ and RSA performance was repeated. Prior to the experiment, the coach had requested that all players would play the same amount of time on the pitch and cover an similar distance. Interchanges were conducted accordingly to achieve this during the matches.

*** Figure 1 near here****

Performance tests (RSA, CMJ)

CMJ-height was measured using the Optojump photoelectric cell system (Microgate, Bolzano, Italy) as previously described (Glatthorn et al. 2011). Players were advised to place their hands at the hips to avoid additional arm swing. The best of three maximal effort jumps was taken for statistical analysis. The RSA-test consisted of 6 maximal 30m efforts, starting every 25 sec as recommended for field hockey players and described elsewhere (Tanner and Gore 2013). Sprint time was assessed using a dual beam sports timing system (Swiftperformance, Wacol, Australia). Gates were placed at the start, 10m, 20m and 30m. Total sprint time was calculated using the sum of all six sprints (total sprint time). The test-retest coefficient of variation for youth male team-sport athletes tested in our laboratory is 2.8% for CMJ and 1.1% for RSA.

Physical Performance Monitoring during match and training

The physical activity of each match and training session was monitored using a portable positional tracking device (10hz GPS and GLONASS) with integrated 3D-Accelerometer, 3D-Gyroscope and 3D-Magnetometer using a sampling rate of 100hz, respectively (OptimEye S5, Catapult sports, Melbourne, Australia). Each player's individually assigned device was worn at the upper back between the left and right scapulae in a custom-made vest (Catapult sports). All devices were turned on at least 30 min before exercise for satellite connection. During data collection the average number of satellites and horizontal dilution of precision per unit (mean ± SD) were 12.0 ± 0.0 and 0.61 ± 0.01, indicating an almost ideal signal quality (Malone et al. 2017).During matches, the players' rotations were precisely documented. After recording, data was downloaded, analysed and reported using the appending software (OpenField v1.17.0). Goalkeepers were excluded from statistical analysis. Bench time of the field players was excluded and values calculated for time on pitch only, as described previously and recommended for time-depended variables in field hockey (White and MacFarlane 2013, Ihsan et al. 2017). Thresholds for six velocity zones (VZ) were matched with previously published investigations in field hockey (VZ1, < 6 $km \cdot h^{-1}$; VZ2, 6 – 11 $km \cdot h^{-1}$; VZ3, 11 – 15 $km \cdot h^{-1}$; VZ4, 15 – 19 $km \cdot h^{-1}$; VZ5, 19 – 23 $km \cdot h^{-1}$; VZ6, > 23 $km \cdot h^{-1}$) (White and MacFarlane 2015, White and MacFarlane 2013, Lythe and Kilding 2011). The time spend in each VZ was calculated as percentage of time on pitch. HSD was measured for speeds above 19 $km \cdot h^{-1}$. The software's inertial movement analysis was used to detect accelerations (ACC) and decelerations (DEC) above 2.5 $m \cdot s^{-2}$ and explosive efforts (ExE), defined as the sum of accelerations, decelerations, changes of direction to the left and right above 3.5 $m \cdot s^{-2}$. TD, HSD, ACC, DEC and ExE were normalised to one minute for comparison.

30 min after the end of each exercise, players were asked to rate their perceived exertion of the previous session ($RPE_{session}$) on a 1 – 10 Borg scale (Foster et al. 2001).

Cold-water immersion and passive recovery

15 minutes after each match or training on days 1 – 4 the CWI-group fully immersed themselves into an ice-water barrel for 5 minutes, with only the head out of the water. The barrels were prepared with crushed ice to a water temperature between 5 and 8°C (6.4 ± 0.8°C). During immersion, the temperature was frequently controlled and ice added if necessary. Players were instructed to slowly move their arms and legs to avoid the formation of warmer water layers around the body. Similar protocols have been used extensively elsewhere (Ingram et al. 2009, Rowsell et al. 2009, Costello et al. 2012). During the same time, the CON-group remained passive and seated at room temperature. Afterwards, the whole team continued with the schedule of the tournament together.

Mean Skin temperature

Skin temperature was assessed by means of a thermoimaging camera (Testo 880, Testo GmbH, Vienna, Austria) as described elsewhere (Moreira et al. 2017). Photos were taken of the trunk, thigh and lower arm before and after CWI and analysed using the appending software (IRsoft Version 3.1 SP3, Testo GmbH, Vienna, Austria). Mean skin temperature (T_{skin}) was calculated using the Burton (Burton 1935) equation: $T_{skin} = 0.5\ T_{trunk} + 0.36\ T_{thigh} + 0.14\ T_{arm}$.

Biomarkers

Every morning 300 µL of capillary blood was collected from the earlobe of each athlete, transferred in a heparinized centrifuge tube, centrifuged for 2 minutes and immediately analysed for serum levels in Creatinkinase (CK), Lactate-Dehydrogenase (LDH) and Blood Urea Nitrogen (BUN) using a mobile Point-of-care device (Spotchem EZ SP-4430, Axonlab, Baden-Daettwil, Germany). Serum levels were determined by optical measurement of reflection intensity (at 550 or 610 nm) for a reagent colour reaction on three single reagent strips. The reagent strip is composed of a multi-layered test field containing reagents necessary to generate a colour that is quantified by reflectance spectrophotometry. The precision (CV %) of consecutive replicate measurements was 3.8% for CK (94.7 $U \cdot L^{-1}$), 3.1 % for BUN (6.1 $mmol \cdot L^{-1}$) and 3.7% for LDH (322.9 $U \cdot L^{-1}$).

Psychological questionnaires, quality of sleep and Pain scale

Every morning before breakfast, the players answered a questionnaire assessing their acute state of recovery and stress. To avoid misunderstanding and translational problems a questionnaire in German language was chosen, that has already been validated in field hockey (Hitzschke et al. 2015). The items of the “Short Recovery and Stress Scale for Sport” were rated on a scale from 0 (“not at all”) to 6 (“absolutely”). Furthermore, players were asked to rate the quality of last nights’ sleep on a scale from 1 (“very good”) to 6 (“very bad”).

Moreover, DOMS was measured every morning and evening, using a 100 mm visual analog scale, ranging from 0 (“no soreness”) to 100 (“severe soreness”) (Williamson and Hoggart 2005). The players rated their individual DOMS after slowly sitting down and standing up from a chair (knee angle approximately 90°).

Heart rate recovery test

A heart rate recovery test was included into the warm-up session before each match or training. On an indoor pitch (length: 50m) the entire team ran for 5 min at a constant speed of 9 km/h, controlled by a digital metronome, followed by sitting in a relaxed position for another 5 min. Heart rate was recorded continuously using a mobile team system (Acentas GmbH, Hörgertshausen, Germany). Exercise heart rate (HR_{ex}), defined as the average heart rate during the last 30 seconds and heart rate recovery (HRR), defined as the difference between HR_{ex} and heart rate after one minute of recovery were calculated as described elsewhere (Buchheit 2014, Borresen and Lambert 2007). HR_{ex} was expressed as percentage of the players' individual maximal HR, HRR was expressed as percentage of HR_{ex}.

Statistical analysis

All statistical tests were carried out using the Statistica software package for Windows® (version 13.0, StatSoft Inc., Tulsa, OK, U.S.A). The distribution of data was assessed using descriptive methods (skewness, outliers, and distribution plots) and inferential statistics (Shapiro–Wilk test). Normal distribution was observed for all parameters except CK. Normally distributed data is presented as mean values ± standard deviations (SD), and mean differences (MD) with 95% confidence intervals for performance tests and distribution of velocity zones. Data deviating from normal distribution is presented as median and inner-quartile range (Q_{25} and Q_{75}). A two way (treatment [CWI, CON] * time [Days 1-5]) repeated-measures analysis of variance (ANOVA) was applied to compare all biomarkers (CK, LDH, BUN), Questionnaires (perceived recovery, perceived stress, quality of sleep, DOMS), heart rate recovery tests (HR_{ex}, HRR), performance tests (RSA, CMJ) and tracking data (time on pitch, total distance, normalised distance, HSD, ACC, DEC and ExE). If main effects for time, intervention or interaction were identified, Bonferroni post-hoc analysis was applied where appropriate. Student paired t-tests were used for analysis of percentage time spend in each velocity zone during tournament matches (days 3-5) as well as the effect of CWI on T_{skin} (pre vs. post). Statistical significance was accepted at $p < 0.05$.

Results

Tracking data

All GPS and accelerometer-based parameters are presented in Table 1 and 2 (means ± SD). All parameters (time on pitch, TD, normalised distance, normalised HSD, normalised DEC) except normalised ACC ($p = 0.21$) and normalised ExE ($p = 0.62$) significantly increased from day 1 to day 5 ($p < 0.01$). However, this is most likely related to the extended training duration on day 2. There were no significant intervention or interaction effects (all $p > 0.05$) (Table 1). During tournament matches there were also no differences (all $p > 0.05$) between CWI and CON in time spent in each velocity zone (Table 2).

*** Table 1 and 2 near here****

Performance tests

There were no time, interaction or intervention effects (all $p > 0.05$) in RSA total sprint time (mean ± SD; mean difference [95% CI]) from day 1 (CWI: 26.23 ± 1.06 s, CON: 26.05

± 0.69 s; MD: 0.18 [-0.78 – 1.14]) to day 5 (CWI: 26.37 ± 1.06 s, CON: 26.34 ± 0.73 s; MD: 0.04 [-0.86 – 0.92]). The same results (all $p > 0.05$) were observed in CMJ with similarly no differences from day 1 (CON: 42.06-± 3.48 cm, CWI: 41.37 ± 5.31 cm; MD: 0.69 [-3.71 – 5.09])to day 5 (CON: 41.82 ± 3.64 cm, CWI: 41.59 ± 4.61 cm; MD: 0.23 [-3.84 – 4.30]), respectively.

Heart rate recovery / Questionnaires

The results for the daily measurements of the heart rate recovery and questionnaires are detailed in Table 3. Throughout the course of the tournament $RPE_{session}$ and perceived stress increased, while perceived recovery, HR_{ex} and HRR decreased (all $p < 0.05$). However, no significant intervention or interaction effects were observed in heart rate recovery- or in questionnaire data (all $p > 0.05$). DOMS (Figure 2) increased over time ($p < 0.01$), but no intervention ($p = 0.09$) and interaction ($p = 0.41$) effect was evident.

*** Table 3 and Figure 2 near here****

Biomarkers

Serum biomarkers data for CK, LDH and BUN is presented in Figure 3. CK increased over time ($p < 0.01$), but no other significant differences were observed (all $p > 0.05$).

*** Figure 3 near here****

CWI - Mean skin temperature

T_{skin} was significantly reduced ($p < 0.01$; $d = 11.5$) from 29.8 ± 1.3 °C to 14.9 ± 1.3 °C immediately after each application of CWI.

Discussion

The present study is the first to delineate the effects of daily post exercise CWI on performance capacity, biomarkers of muscle damage and metabolic load, fatigue, and recovery during a 5-day junior elite field hockey tournament. The main findings of the present study are: (1) in support of our hypothesis, daily CWI did not alter performance parameters during consecutive matches, (2) regardless of recovery intervention, elite youth field hockey players were able to maintain match-to-match performance, (3) exercise-induced alterations in biomarkers were not attenuated by CWI, and (4) contrary to our second hypothesis, CWI did not improve perceptual recovery. Collectively, these data suggest that daily post exercise CWI has no beneficial effects during a 5-day tournament and therefore its usage is not recommended in international standard male junior field hockey players

It has previously been reported that CWI might be able to reduce fatigue associated decrements in physical performance (i.e. TD and HSD) during consecutive tournament soccer matches in junior males (Rowsell et al. 2011). The findings of the current study suggest that these benefits may not be extended to field hockey (Table 1 and 2), as elite youth athletes were able to maintain their physical match performance even without the use of CWI. These contrasting findings might be explained by the large differences in running characteristics observed between both sports. Total duration is less in field hockey (~ 30 min) and unlimited interchanges allow individual recovery breaks and higher intensities on the pitch (Spencer et al. 2005). However, the present data suggests that the repeated high intensity exercise throughout the tournament did not lead to reduced match running performance or exercise intensity. Distribution of percentage durations per velocity zones was constant over the course of the tournament and significant time effects in time on pitch, TD and normalised distance, HSD and DEC were caused by day 2 training session. These results corroborate the findings of Jennings et al. (Jennings et al. 2012) and Ihsan et al (Ihsan et al. 2017), who also reported that elite hockey players were able to maintain exercise intensity when playing six matches in nine days. Contrary, Spencer and colleagues (Spencer et al. 2005) described a decrease in jogging and increase in walking duration in three subsequent field-hockey matches within four days. It must be acknowledged that match performance variables may not reflect the true status of recovery, as tactical requirements may result in high between match variability (Gregson et al. 2010). Regardless, it appears likely that young elite field hockey players are able to maintain their physical performance throughout consecutive matches.

This is further supported by the results of the jump and repeated sprint performance outcomes (CMJ and RSA). These tests have previously been used to monitor fatigue and recovery state in team sports, as alterations are associated with training and match performance (Thorpe et al. 2015, Buchheit et al. 2013, Claudino et al. 2017, Ingram et al. 2009). In contrast to observations in other team sport tournaments (Rowsell et al. 2009, Montgomery et al. 2008), performance in CMJ remained consistent from day 1 to day 5 and RSA was only reduced by ~1%, with no differences between CWI and CON-group. These results indicate that the 5-day tournament did not induce accumulated neuromuscular fatigue and CWI had no impact on athletic performance.

Significant reductions in HR_{ex} and HRR were observed in the present study in the CWI- and CON-groups, with the lowest values recorded on day 3 and 4. This is counterintuitive, as lower HR_{ex} and HRR (when expressed as $\%HR_{ex}$) is typically associated with improved fitness and reduced fatigue (Daanen et al. 2012, Buchheit et al. 2013). Comparable data have been explained as demonstrating symptoms of overreaching (Borresen and Lambert 2007); however, this is very unlikely in the present study as physical performance was maintained throughout the tournament. Further, these international standard players were highly trained prior to the start of the tournament. CWI has been proposed to increase parasympathetic activity along with cardiac output (Ihsan et al. 2016), consequently lower HR_{ex} and HRR could have been expected in the CWI-group. However, CWI did not induce changes in exercise- induced alterations of heart-rate derived variables compared to CON.

Post-exercise ratings of perceived exertion ($RPE_{session}$) increased from day 1 to 4 in both groups and slightly dropped on day 5 (Table 3). As performance values and exercise intensity were on the same level throughout tournament matches, this increase might be an indicator for increasing perceptual fatigue as shown during a 5-day soccer tournament as well (Rowsell et al. 2009). DOMS also accumulated throughout the course of the tournament. Days 3-5 showed significantly elevated levels compared to baseline, however, there were no intervention or interaction effects in this field based analysis (Figure 2). Even though some studies (Pournot et al. 2011, Corbett et al. 2012) reported no effects of CWI on DOMS as well, several empirical laboratory and field based studies (Ascensao et al. 2011, Bailey et al. 2007, Rowsell et al. 2009, Ingram et al. 2009) and reviews (Ihsan et al. 2016, Hohenauer et al. 2015, Bleakley et al. 2012, Leeder et al.

2012) suggest that post exercise CWI is effective in reducing DOMS. These findings may be explained by the training status of the international level athletes, which one would expect to result in relatively limited DOMS observed in the current study. Furthermore, DOMS typically peaks ~48 hrs after exercise (Goodall and Howatson 2008), however the team was required to daily, thus the time course for peak DOMS of a single exercise is difficult to identify. Moreover, as exercise itself has been shown to reduce DOMS (Corbett et al. 2012), it is plausible that the exercise may have led to an attenuation of DOMS in the CON- group. Perceived stress and recovery remained similar throughout the tournament and only increased from day 4 to day 5. As the final match decided about winning the tournament, these time effects are most likely related to this. The exercise itself and the recovery modality had no influence on the players' ratings of perceived stress, recovery, or quality of sleep (Table 3).

Findings regarding the effects of CWI on exercise- induced alterations of biomarkers associated with muscle damage and inflammation are contradictory in the literature [for review see (Leeder et al. 2012, Bleakley et al. 2012, Hohenauer et al. 2015, Ihsan et al. 2016)]. For example, several studies have demonstrated decreased levels of CK, Myoglobin or C-reactive Protein compared to thermoneutral or contrast water immersion and passive control (Ascensao et al. 2011, Pournot et al. 2011, Bailey et al. 2007) while others reported no change (Ingram et al. 2009, Pointon et al. 2012, Corbett et al. 2012). In line with the current investigation Rowsell at al. (Rowsell et al. 2009) found no effect on CK-clearance following the use of CWI after 5-day soccer tournament. These finding corroborates the current results as CK increased from day 1 to 2 and remained elevated throughout the course of the tournament, indicating high muscular load in both groups;

yet, CWI did not ameliorate the elevation in CK. However, no changes in LDH or BUN were observed (Figure 3). Similar differences in CK and LDH responses to exercise have been reported before and are potentially attributed to the different structural areas where they are sequestered within the muscle sarcomere (Pournot et al. 2011). Nevertheless, it could be argued that exercise intensity over the course of the five days was not severe enough to induce a higher protein turnover rate, which would have been indicated by elevated levels in BUN (Meyer and Meister 2011).

The present study has limitations that warrant mention. Firstly, we acknowledge the small sample size of n=18. However, the entire national squad participated in the study; therefore, this sample represent the largest number of international level athletes we were able to recruit. Secondly, as indicated by elevated levels in CK, DOMS and stress at baseline, the athletes did not commence the tournament in a completely ‘rested’ state. This is not surprising and reflects the intense schedule of elite junior team sport athletes that participate in tournaments or international competitions alongside, or immediately after, their regular season. Thirdly, performance data (i.e. CMJ and RSA) was assessed after the athletes arrived on site (circa 10 am) on day 1 and on day 5 three hours following the final match of the tournament (circa 4 pm). We acknowledge that the data may be reflective of this; however, again this represents the challenge of conducting applied research on international athletes and working within their time schedules. However, both the CWI and the control groups were randomised and we do not believe this invalidates our findings regarding the effectiveness, or lack thereof, of the CWI intervention. Finally, we acknowledge that additional follow up data after the tournament (i.e. day 6 and 7) would have added additional insights, but this was not feasible as the athletes returned home, all across the country, after the tournament.

Conclusion

Despite elevated levels of CK, RPE and DOMS, several parameters (i.e. LDH, BUN, perceived recovery and stress, quality of sleep) were not altered over the course of the 5-day tournament. This suggests that there was an absence of severe cumulative fatigue and/or the international standard athletes were sufficiently capable of completing and recovering from the intensive training load, as indicated by maintained physical performance. The results of the present study also indicate that CWI had no beneficial effects on physical performance, perceptual wellbeing, or biomarkers associated with muscle damage compared to passive recovery. In conclusion, the application of daily CWI appears to be superfluous and we do not recommend its use in elite junior field-hockey players during a 5-day tournament.

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Disclosure statement

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FIGURE CAPTIONS

Fig. 1 Schematic presentation of the study design. CWI: Cold-water immersion; RSA: Repeated sprint ability; CMJ: Counter movement jump; DOMS: rating of delayed onset muscle soreness

Fig. 2 Perceived ratings (mean ± SD) of delayed onset muscle soreness (DOMS) in the morning (pre) and evening (post) of each day (Days 1-5). * $P < 0.05$ time effects compared to baseline (day 1 pre), for both interventions (cold-water immersion [CWI] and control [CON]) combined

Fig. 3 Serum concentrations of Creatinkinase (CK) (median ± inner quartile range), Lactate Dehydrogenase (LDH) and Blood Urea Nitrogen (BUN) (mean ± SD) in the morning of each day (Days 1-5). * $P < 0.05$ time effects compared to baseline (day 1), for both interventions (cold-water immersion [CWI] and control [CON]) combined

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Table 1 Comparison of external load parameters (mean ± SD) between recovery modalities cold-water immersion (CWI) and control (CON)

Variable	Intervention	Day 1 – FM	Day 2 – TR	Day 3 – TM 1	Day 4 – TM 2	Day 5 – TM 3	p-value [time]	p-value [int.]	p-value [time*int.]
Time on pitch [min]	CWI	46.6 ± 10.4	120.0 ± 0.0	53.5 ± 6.0	46.5 ± 11.1	51.0 ± 5.4	< 0.01	0.87	0.61
	CON	42.3 ± 5.4	120.0 ± 0.0	51.5 ± 6.4	47.6 ± 8.7	54.2 ± 8.9			
Total distance [m]	CWI	5487 ± 1013	6883 ± 690	6193 ± 800	5614 ± 1408	5765 ± 614	< 0.01	0.81	0.70
	CON	5146 ± 697	6990 ± 394	5940 ± 956	5337 ± 976	6185 ± 1082			
Normalised distance [m·min^{-1}]	CWI	119.3 ± 11.0	57.4 ± 5.7	115.8 ± 7.2	120.5 ± 6.2	113.3 ± 7.0	< 0.01	0.82	0.24
	CON	121.9 ± 7.6	58.2 ± 3.3	115.3 ± 12.8	112.8 ± 11.8	114.0 ± 10.6			
Normalised HSD [n·min^{-1}]	CWI	8.86 ± 4.63	2.16 ± 1.02	7.61 ± 3.81	10.02 ± 4.63	8.40 ± 2.60	< 0.01	0.65	0.83
	CON	10.32 ± 2.14	2.38 ± 0.74	8.56 ± 2.27	10.43 ± 3.14	7.60 ± 1.79			
Normalised ACC [n·min^{-1}]	CWI	0.29 ± 0.09	0.22 ± 0.06	0.25 ± 0.07	0.25 ± 0.13	0.18 ± 0.05	0.21	0.10	0.54
	CON	0.19 ± 0.06	0.17 ± 0.07	0.13 ± 0.07	0.13 ± 0.07	0.23 ± 0.08			
Normalised DEC [n·min^{-1}]	CWI	0.35 ± 0.17	0.14 ± 0.08	0.33 ± 0.16	0.38 ± 0.10	0.30 ± 0.12	< 0.01	0.63	0.42
	CON	0.28 ± 0.12	0.18 ± 0.08	0.31 ± 0.11	0.31 ± 0.10	0.32 ± 0.09			
Normalised ExE [n·min^{-1}]	CWI	0.42 ± 0.12	0.35 ± 0.08	0.46 ± 0.15	0.37 ± 0.09	0.32 ± 0.08	0.62	0.19	0.52
	CON	0.29 ± 0.08	0.33 ± 0.08	0.32 ± 0.12	0.41 ± 0.17	0.39 ± 0.10			

FM: friendly match; TR: training; TM: tournament match; HSD: high speed distance; ACC: accelerations; DEC: decelerations; ExE: explosive efforts;

Int.: intervention

Table 2 Comparison of percentage duration [mean ± SD; MD and 95% CI] spend in each velocity zone during tournament matches 1-3 combined

Velocity zone	CWI	CON	MD [95% CI]	p- value

< 6 $km \cdot h^{-1}$	54.8 ± 3.7	56.4 ± 6.0	1.6 [-6.5–3.3]	0.34
6 – 11 $km \cdot h^{-1}$	24.4 ± 2.1	23.3 ± 2.8	1.1 [-1.3-3.5]	0.18
11 – 15 $km \cdot h^{-1}$	12.9 ± 1.8	12.2 ± 2.6	0.7 [-1.5-2.9]	0.30
15 – 19 $km \cdot h^{-1}$	5.4 ± 1.2	5.5 ± 1.5	0.1 [-1.4-1.2]	0.77
19 – 23 $km \cdot h^{-1}$	1.9 ± 0.7	1.9 ± 0.5	0.0 [-0.6-0.6]	0.82
> 23 $km \cdot h^{-1}$	0.5 ± 0.4	0.5 ± 0.3	0.0 [-0.3-0.3]	0.49

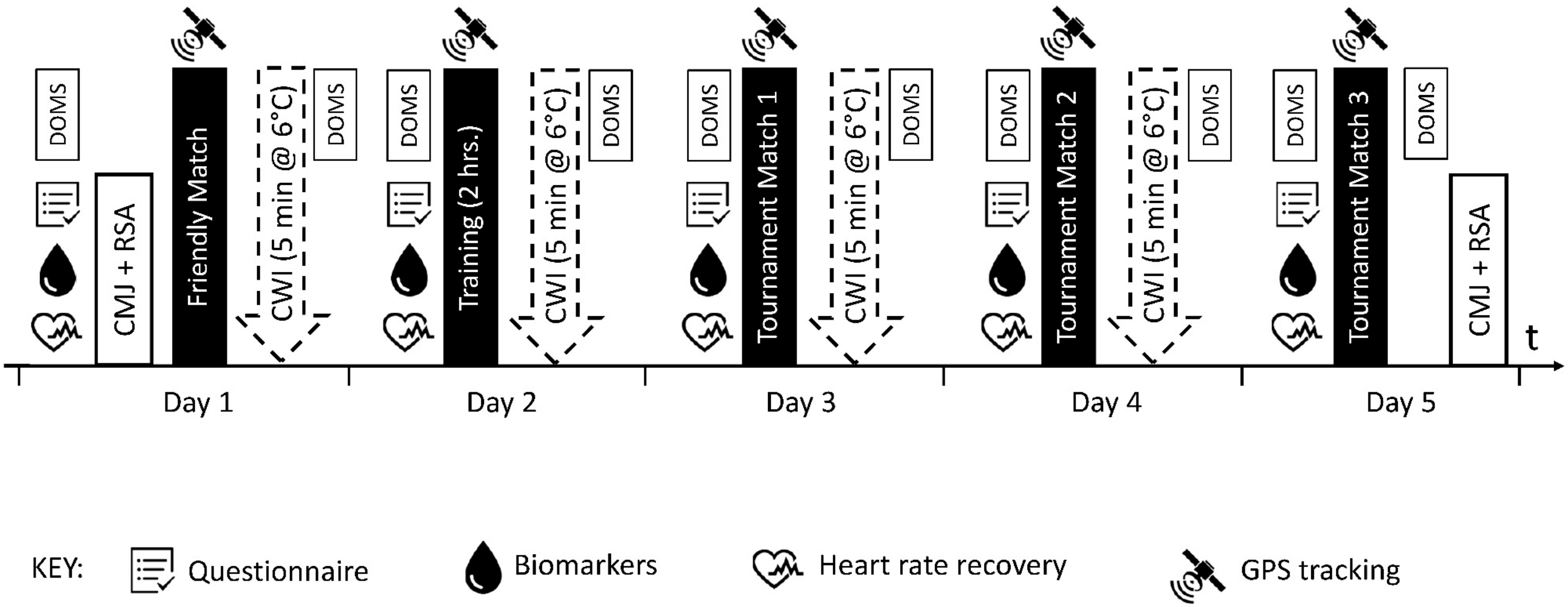
CWI: cold water immersion; CON: control

Table 3 Comparison of perceptual and HR-based parameters (mean ± SD) between recovery modalities cold-water immersion (CWI) and control (CON)

Variable	Intervention	Day 1 – FM	Day 2 – TR	Day 3 – TM 1	Day 4 – TM 2	Day 5 – TM 3	p-value [time]	p-value [int.]	p-value [time*int.]
$RPE_{session}$	CWI	4.9 ± 0.6	5.1 ± 0.7	5.7 ± 1.3	6.8 ± 1.7	6.0 ± 1.3			
					*	*	< 0.01	0.58	0.81
[AU]	CON	5.2 ± 1.0	5.7 ± 0.7	5.7 ± 0.7	6.7 ± 1.2	6.3 ± 1.2			
Quality of sleep	CWI	2.6 ± 1.2	2.6 ± 1.0	2.7 ± 0.8	2.3 ± 0.9	2.7 ± 1.1			
							0.38	0.67	0.81
[AU]	CON	2.8 ± 1.2	2.2 ± 0.6	3.1 ± 1.3	2.3 ± 0.8	2.9 ± 0.7			
Perceived stress	CWI	2.6 ± 0.7	2.1 ± 0.3	2.1 ± 0.4	2.2 ± 1.0	2.8 ± 1.2			
						*	0.02	0.87	0.38
[AU]	CON	2.2 ± 0.7	2.5 ± 0.6	2.3 ± 1.0	2.0 ± 0.9	2.8 ± 0.7			
Perceived recovery	CWI	3.6 ± 0.5	3.6 ± 0.5	4.0 ± 0.6	3.9 ± 0.9	3.1 ± 1.0			
						*	< 0.01	0.82	0.85
[AU]	CON	3.7 ± 0.8	3.6 ± 0.7	3.7 ± 0.8	3.9 ±0.8	3.1 ± 0.6			
HR_{ex}	CWI	77.5 ± 5.0	79.5 ± 4.0	73.6 ± 4.4	73.2 ± 4.9	76.0 ± 3.2			
				*	*		< 0.01	0.67	0.69
[$\%HR_{max}$]	CON	77.2 ± 3.9	80.6 ± 4.3	75.8 ± 4.1	73.9 ± 4.8	76.2 ± 3.3			
HRR	CWI	67.4 ± 3.2	65.4 ± 4.0	62.8 ± 6.3	60.3 ± 6.1	62.8 ± 5.0			
				*	*		< 0.01	0.36	0.26
[$\%HR_{ex}$]	CON	70.1 ± 3.7	64.7 ± 3.8	62.4 ± 6.0	63.8 ± 6.5	66.4 ± 5.3			

FM: friendly match; TR: training; TM: tournament match; RPE: rating perceived excertion; HR_{ex}: exercise heart rate; HRmax: maximum heart rate;

HRR: heart rate recovery; Int.: intervention; * indicates significant time effects ($p < 0.05$) compared to Day 1



DOMS
CMJ + RSA
Friendly Match
CWI (5 min @ 6°C)
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Training (2 hrs.)
CWI (5 min @ 6°C)
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Tournament Match 1
CWI (5 min @ 6°C)
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Tournament Match 2
CWI (5 min @ 6°C)
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CMJ + RSA
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Day 1
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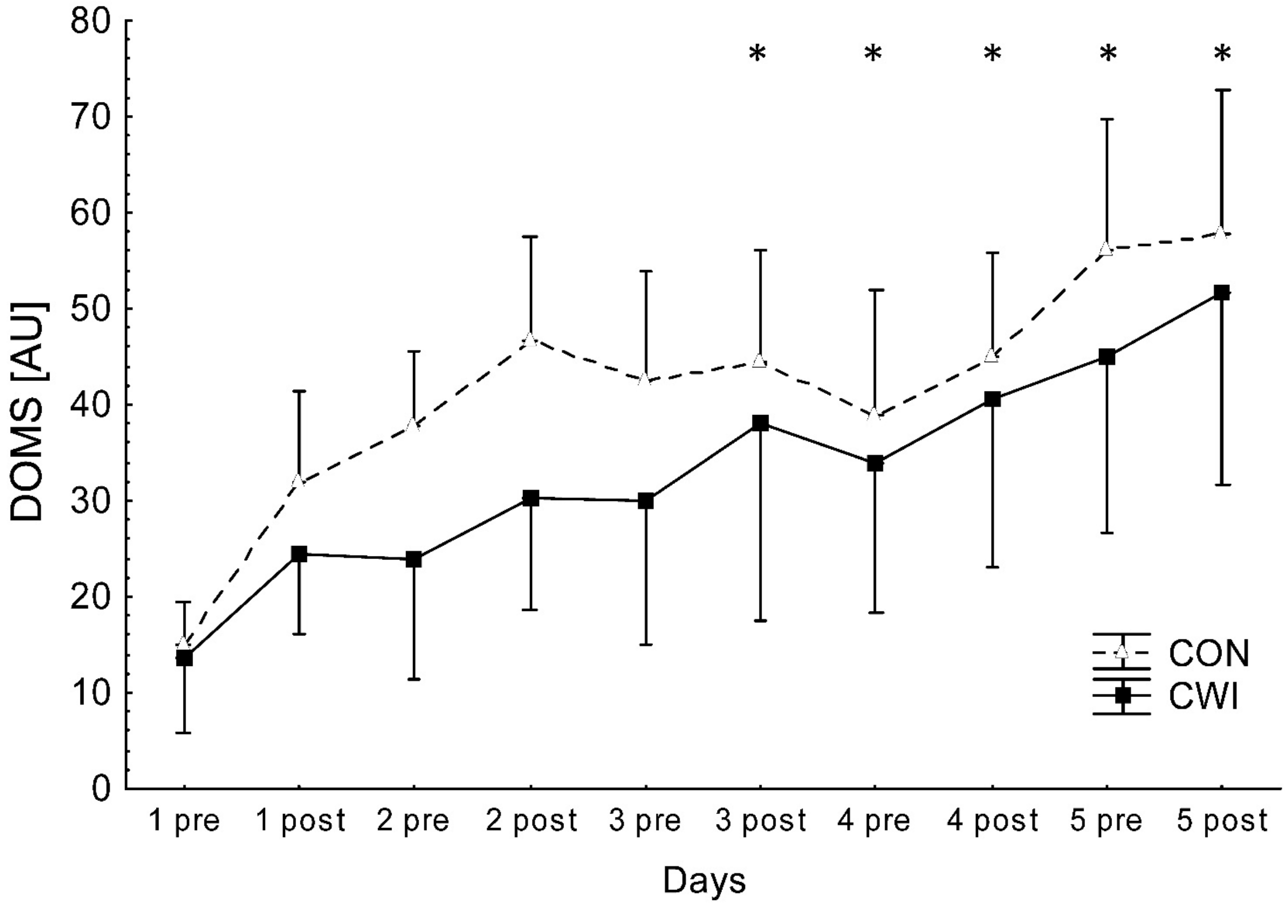
KEY:
Questionnaire
Biomarkers
Heart rate recovery
GPS tracking



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DOMS [AU]
* * * * *
CON
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1 pre
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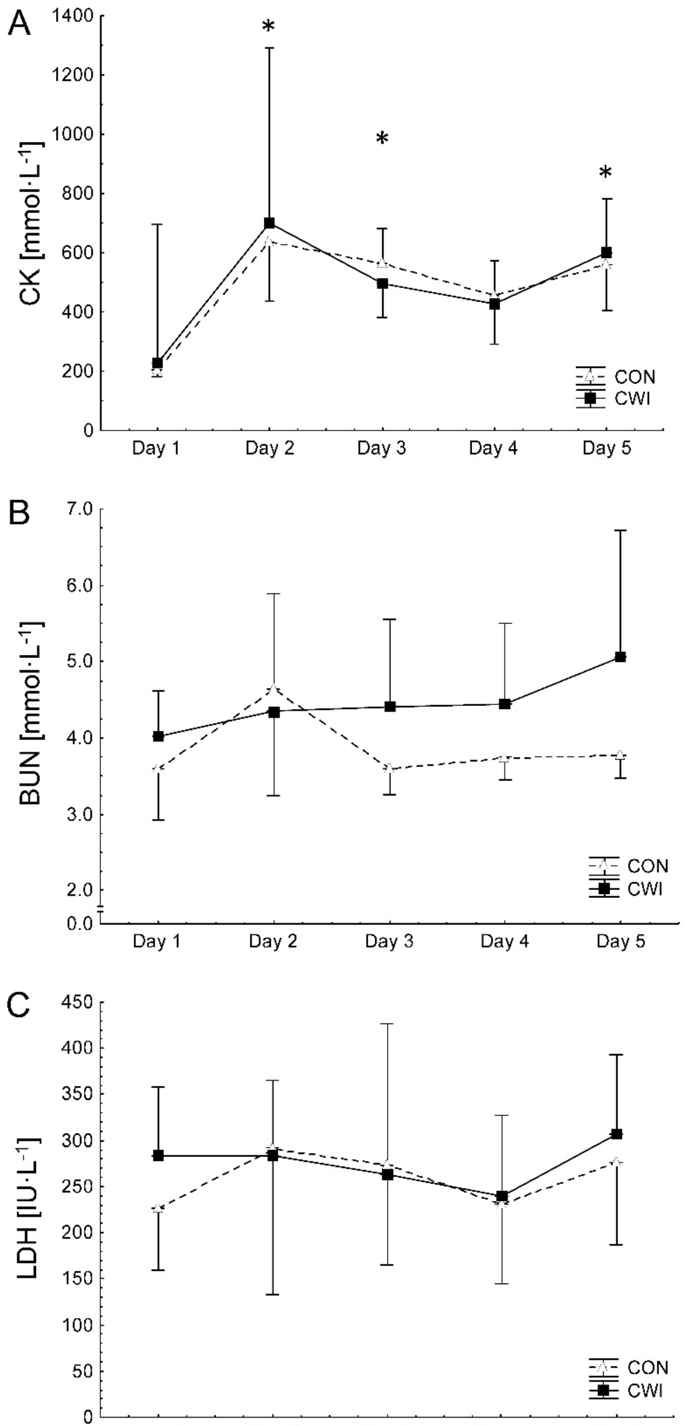
5 post
Days

636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CON
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Day 5
C
LDH [IU·L-1]
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400
350
300
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200
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100
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0
CON
CWI