***Title of the article*:**

A 2.5 min cold water immersion improves prolonged intermittent sprint performance.

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Abstract

Objectives: We investigated if cold water immersion (CWI) affects exercise performance during a prolonged intermittent sprint test (IST), designed to mimic activity patterns of team-sports. *Design*: randomized-crossover design. *Methods*: Ten male team-sport players completed 3 IST protocols (two 40-min "halves" of repeated 2-min blocks consisting of a 8-s "all-out" sprint, 100-s active recovery and 12-s rest) on a cycle ergometer at normothermic conditions. Each "half" was separated by a 15 min recovery period of either: i) passive rest, ii) 5-min CWI at 8°C (CWI-5) or iii) 2.5-min CWI at 8°C (CWI-2.5), in a random counterbalanced order. *Results*: Physical performance, core temperature (T_{core}) and heart rate were not different among conditions in the first half. In the passive rest trial, total work (TW) and peak power (PP) were lower during the second half (TW: 5.04±1.11 kJ; PP: 929±286 W) than the first half (TW: 5.66±1.02 kJ; PP: 1009±266 W); while TW and PP were not different between halves following CWI-5 (first half, TW: 5.34±1.02 kJ, PP: 1016±283 W; second half, TW: 5.19±1.38 kJ; PP: 996±318 W) and CWI-2.5 (first half, TW: 5.47±1.19 kJ, PP: 966±261 W; second half, TW: 5.25±1.17 kJ; PP: 952±231 W). T_{core} was lower until the 20th minute of the second half after CWI-5 and CWI-2.5 compared with passive rest. *Conclusions*: A post-exercise 2.5- to 5-min CWI attenuates the reductions in prolonged sprint performance that occur in the second half of team sports, due, at least partly, to reductions in core temperature and associated increase in heat storage.

Key words: Exercise recovery; half-time interval; hydrotherapy; team-sport; power output

1. Introduction

The majority of intermittent team sports alternate low-intensity endurance exercise bouts with short-duration high-intensity efforts over a duration of a match. Extensive match play analysis has revealed that performance of high-intensity exercise efforts is significantly reduced during the second half of competitive matches in many team sports (i.e. soccer,[1] rugby,[2] futsal[3] etc.). Thus, in order to ameliorate these performance decrements in the second half an optimal half-time recovery strategy is critical for team sport players.

Recent studies have demonstrated that cold water immersion (CWI) is an effective recovery intervention when employed between two equal bouts of nondamaging concentric high-intensity endurance exercise to maximize performance in the second bout.[4-7] This beneficial effect seems to be superior than the effects observed following other common recovery interventions such as contrast water therapy, active recovery or thermoneutral water immersion.[4, 8] The beneficial effects of CWI on subsequent performance have been proposed to be mediated by an increase in heat storage capacity,[9] an increase in venous return induced by the hydrostatic pressure or cold stimulus of water[10] and/or reactivation of cardiac parasympathetic activity.[11]

Most of these investigations into the effect of CWI on subsequent intense endurance performance between two identical exercise bouts, however, have utilized recovery intervals unsuitable for team sport matches, ranging from 40 to 55 min,[4, 7, 8] with the time interval between the end of the immersion and subsequent exercise bout sometimes exceeding 1-2 h[11, 12]. To our knowledge, only two previous studies have investigated the effects of post-exercise CWI carried out within a recovery interval relevant to half time (~15 min), on subsequent high-intensity endurance exercise performance carried out immediately after recovery.[13, 14] In both of these studies, however, the total duration of the high-intensity exercise protocols (lasting ~6[13] and ~7 min[14]) was much shorter than the team-sport game (i.e. 2 x 40 min such as in filed hockey or rugby) and did not replicate the metabolic demands of team sport games. In addition, participants carried out an active warm up lasting 12[14] to 30 min[13] prior to completing the high-intensity bouts,

Accordingly, in order to better understand the effects of CWI in subsequent performance within a team-sport match play scenario, the aim of the present study was to investigate the effect of a brief CWI (2.5 or 5 min) employed within a 15 min recovery period between two equal 'halves' of 40 min on the second 'half' of an intermittent sprint test (IST) protocol designed to replicate the average sprint profile and metabolic demands of a typical team sport game. It was hypothesized that both CWI interventions would ameliorate the reductions in physical performance of the second half of the IST when compared with a passive control condition.

2. Methods

Ten male recreational team-sport players from local rugby (n = 3), soccer (n = 5) and Gaelic football (n = 2) teams (mean ± SD; age: 22 ± 2 year; height: 182 ± 10 cm; body mass: 85 ± 14 kg, peak oxygen uptake ($\dot{V}O_{2peak}$): 46.1 ± 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$, peak power ($PO_{peak}$): 309 ± 44 W) took part in this study. Each participant gave written informed consent to participate in this study, which was conducted according to the Declaration of Helsinki and approved by the Faculty of Health Science Research Ethics Committee, Trinity College Dublin.

Following a preliminary incremental cycling test and familiarization (visit 1), participants were required to carry out 3 separate randomized trials (visits 2-4) separated by a minimum of two days. All laboratory sessions were completed within 7 weeks. Each trial required the participants to complete an IST consisting of two 40-min equal halves separated by a randomized 15 min recovery period. Participants' weekly training regimen was similar and it was maintained throughout the study. All participants were instructed to complete a nonstandardized 24 h food and fluid recall upon presentation to the first laboratory session and to include a meal consisting of approximately 200 g of carbohydrate 3 h prior to this session. They were then instructed to replicate this food and fluid intake as closely as possible in the 24 h prior to their subsequent experimental sessions. Adequate hydration status was ensured at the start of each visit measuring urine specific gravity (accepted euhydration range: 1.000 to 1.020) using an optical refractometer (Bellingham & Stanley, Hants, UK). All experimental sessions were held at the same time of day at a normothermic ambient temperature (20 ± 1°C, relative humidity: 66%) and participants were required to refrain from heavy exercise and caffeine or alcohol consumption for 24 h and 12 h, respectively, before each laboratory visit. During all trials (excluding recovery periods), participants were cooled with a 300-mm diameter fan (Micromark, UK) placed 1 m in front of them that produced an air flow equivalent to ~3 km.h^{-1}. All exercise sessions were performed in the upright position using an electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, The Netherlands).

A ramp incremental test (following increments of 20W/min) to failure was performed to determine $\dot{V}O_{2peak}$. The individual power output and $\dot{V}O_2$ data from the ramp test were used to establish the exercise intensity during the IST. After the ramp test, participants were familiarized with the intermittent sprint protocol and CWI. The IST was based on a motion analysis study of international field hockey[15] and is an extension of protocols described previously,[16, 17] which were designed to mimic the average sprint profile of a typical team-sport game given that exercise intensities and sprint activities observed during elite field hockey are similar to those of elite soccer and rugby.[15] After a 10-min standardised warm-up (cycling 5 min at 50% $\dot{V}O_{2peak}$, followed by 5 min at 60% $\dot{V}O_{2peak}$), a practice 2-min block of the IST protocol was carried out. Then, following a 3 min 30 s seated rest participants started the IST which consisted of two 40-min "halves" of intermittent sprint exercise separated by 15 min of recovery. Each half of the IST was divided into 2-min blocks which consisted of a 8-s all-out effort, 100 s of active recovery (at 35% $\dot{V}O_{2peak}$) and 12 s of passive recovery. On two occasions during each half (after sprints 8 and 16), participants completed blocks of 5 x 6-s all-out sprints separated by 14 s of active recovery (at 35% $\dot{V}O_{2peak}$) to simulate the repeated-sprint bouts with short recoveries observed in team-sport games[15]. Despite the fact that the IST was performed on the cycle ergometer, all sprints were performed in the standing position on the front-access. This is relevant as reductions in repeated sprint cycling performance (i.e. % power decrements during 5 x 6 s all-out sprints) on the front access has been shown to be correlated with reductions in repeated sprint running performance (i.e. % time decrements during 15 x 15 m running sprints).[18] In addition, although the cycling IST cannot replicate the exact movement patterns encountered in team sports, it permits a better control of the ambient environmental conditions when compared with field-based running test. Immediately after the first half, participants were allowed to drink a small amount of water (<50 ml), which was consistent during the 3 visits.

In the present study the duration of the all-out efforts (i.e. 8-s and 6-s) was slightly longer than in previous studies (6-s and 4-s in Thompson et al [17], 4-s and 2-s in Bishop et al[16]). This was done to include in the exercise protocol of the present study the ‘high-speed’ running efforts (often defined as running speeds between 19.8 and 25.1 km.hr^{-1} [19]) that make up ~2-3% of total match exposure in team sports,[19] and that were not quantified in the original study by Spencer et al.[15] Each “all-out” effort was conducted using a modified form of the Wingate test (i.e. reducing the 30-s all-out period to 8-s or 6-s maintaining a constant breaking torque of 0.7 Nm) using the Lode ergometer with an appropriate software (LEM module Wingate Test, Lode, Groningen, Netherlands).

On each testing day one of the following recovery interventions were performed in a balanced randomized order: (a) passive un-immersed seated rest, (b) 5 min CWI at 8°C (CWI-5) and (c) 2.5 min CWI at 8°C (CWI-2.5). During the last 3 min of each recovery intervention participants were required to cycle at 50 W. During the CWI-5 trial participants were immersed in a custom built bath (Sturdy Products, Co. Wicklow, Ireland) situated next to the cycling ergometer, between min 3 to 8; and during the CWI-2.5 trials, they were immersed between min 4 to 6.5.During the recovery treatments the level of water was to sternum level while participants were seated upright with their legs slightly bent (~90°) and fully immersed. During the transition to the bath, participants removed cycling shoes, top (i.e. t-shirt), shorts and socks and changed into swimming shorts, changing back into exercise clothing during the second transition. Towels were provided for participants after all water immersion treatments so participants could dry themselves before redressing for the 2nd half. During the passive condition participants sat in the same position in the empty bath. The 8°C water temperature was chosen because it is widely reported characteristic of water immersion for recovery post-exercise.[5,10] The water temperature was monitored with a bench thermometer (TM Electronics Ltd., West Sussex, UK) attached to a type T thermocouple and ice was added to decrease the temperature when needed.

During all cycling tests participants wore a facemask to continuously collect expired air using an online metabolic system (Cosmed Quark CPET, Rome, Italy) and mean $\dot{V}O_2$ was calculated for each half. Heart rate (HR) was recorded second-by-second (S610i, Polar Electro Oy, Finland) and rates of perceived exertion (RPE) were documented using the Borg scale (6 to 20)[20] after the completion of each sprint. Core (gastrointestinal) temperature (T_{core}) was recorded continuously using ingestible body temperature sensors and a hand held data receiver (CorTemp, HQ, Florida, USA). Each participant swallowed the sensor with tepid water approximately 3 h before testing. This method provides a valid index of core temperature in comparison with rectal and oesophageal temperature.[21]

Data are presented as mean ± SD. Total work done (TW), peak power achieved (PP) and mean power achieved (MP) during each 8-s all-out sprint as well as HR, T_{core} and RPE responses were analyzed using a two-way repeated measures ANOVA (trial by time). Similarly, TW, PP, MP and $\dot{V}O_2$ responses achieved in each half were also analyzed using a two-way repeated measures ANOVA. Differences were detected using Holm-Sidak *post-hoc* tests. Statistical analyses were performed using SigmaPlot (v. 12, Systat Software, San Jose, USA). Significance was set at $P < 0.05$. Effect sizes were also calculated using Cohen's *d* to compare the magnitude of the difference in total work done, peak power achieved and mean power achieved between the three trials.[22] Thresholds for effect sizes (ES) were set as the following: <0.19, trivial; 0.20-0.49, small; 0.5-0.79, moderate; >0.8, large; with an effect size of 0.2 being considered as the smallest worthwhile positive effect. Effect size was computed as d = [(mean Ex1 – mean Ex2) / pooled standard deviation].

3. Results

Mean cycling performance responses between the first and second halves (excluding data from the blocks of 5 x 6-s all-out sprints) are shown in Fig 1. There was a trial x time interaction for TW ($P = 0.029$), PP ($P = 0.040$) and MP ($P = 0.028$). Specifically, in the passive rest trial, TW and PP were lower ($P < 0.001$ for both) during the second half than the first half (TW mean difference = -0.62 KJ, 95% CI -0.82 to -0.42; $d = 0.54$; PP mean difference = -80 W, 95% CI -125 to 34, $d = 0.29$); while TW and PP were not significantly different between the first and the second halves following CWI-5 (TW mean difference = -0.15 KJ, 95% CI -0.56 to 0.24; $d = 0.13$; $P = 0.23$; PP mean difference = -20 W, 95% CI -59 to 20, $d = 0.07$; $P = 0.33$) and CWI-2.5 (TW mean difference = -0.22 KJ, 95% CI -0.47 to 0.03; $d = 0.19$; $P = 0.10$; PP mean difference = -14 W, 95% CI -62 to 34, $d = 0.06$; $P = 0.48$). MP was lower in the second compared with the first half in the passive rest trial (mean difference = -76 W, 95% CI -101 to -50; $d = 0.54$, $P < 0.001$) and CWI-5 (mean difference = -35 W, 95% CI -69 to -0.3; $d = 0.25$, $P < 0.02$) but following CWI-2.5, MP was not significantly different between the first and second halves (mean difference = -28 W, 95% CI -60 to 3.3; $d = 0.19$, $P = 0.51$). In all 3 conditions mean $\dot{V}O_2$ was not different during the second half compared with the first half (trial x time interaction, $P = 0.32$). There were no differences in TW, PP, MP or $\dot{V}O_2$ among the 3 conditions within either half. In these analyses data from the blocks of 5 x 6-s all-out sprints were excluded to specifically report the physical performance outcomes from the 8-s all-out sprints; however, when TW, PP, MP and $\dot{V}O_2$ responses between halves were analysed including the 6-s all-out sprints, results were unaffected.

T_{core} and HR responses across all conditions over time are presented in Fig 2. Compared with the passive rest, both CWI-5 and CWI-2.5 induced lower T_{core} responses during the final 10 min of the recovery interval ($P = 0.027 – 0.001$) and during the first 20 min of the second half ($P <$

0.001 for all). For CWI-2.5 T_{core} was still lower than the passive rest ($P < 0.001$) at the sprint 13 of the second half (Fig 2A). HR responses were lower at the onset of the second half in CWI-5 and CWI-2.5 compared with passive rest ($P = 0.022$ and 0.002 respectively) (Fig 2B). There were no significant differences in rates of perceived exertion values during the first or second halves of the IST protocol (results not displayed).

4. Discussion

The main finding of the present study, in accordance with our principal hypothesis, was that both CWI interventions significantly ameliorated (trivial ES for both) the reductions in TW and PP observed in the passive rest (moderate ES) condition in the second half of the intermittent sprint test which was designed to reflect the dynamic activity patterns of a typical team sport game. The shorter CWI protocol (CWI-2.5) also ameliorated the reductions in MP (trivial ES) observed in the passive rest (moderate ES) and CWI-5 (small ES) conditions in the second half of the IST, thus, CWI-2.5 resulted marginally superior than CWI-5. Both CWI treatments evoked reduced T_{core} (and most likely muscle temperature) responses during the majority of the second half exercise protocol, however, these reductions were not severe enough to impair the performance of the subsequent initial all-out sprints.

The ergogenic effects observed in the present study are in agreement with previous studies reporting significant benefits on intense endurance exercise performance immediately following a relatively short CWI period employed after the performance of a previous identical exercise bout, compared with passive and/or active rest in normothermia[4, 5, 7, 14, 23] and hyperthermia.[6, 13] Importantly, to our knowledge, the present study is the first reporting that a 2.5 to 5 min CWI intervention within a 15 min recovery period applicable to half-time intervals in normothermic lab conditions increases subsequent IST compared with passive rest in a protocol that mimics the duration and the work profile of a team-sport match. Previous studies that have assessed the effects of a post-exercise CWI on subsequent all-out sprint cycling when performed immediately after the immersion, deleterious performance effects have been reported compared with passive or active recovery conditions.[24, 25] This is most likely due to impaired contractile apparatus of cooled muscles.[26] However, in these previous studies only 1 to 3 Wingate tests were carried out without any prior warm up, and the duration of the CWI (15 min to 30 min) as well as the duration of the ‘all-out’ efforts (30 s) employed were longer than those employed in the present study (CWI: 2.5 to 5 min; all-out efforts: 6-8 s) where participants carried out a 3 min warm-up immediately prior to the first brief sprint. This suggests that the extent of the reduction in muscle temperature in the present study was likely not severe enough to induce significant reductions in the subsequent initial brief all-out efforts. The fact that 2.5 and 5 min of CWI induced similar benefits in IST performance suggests that an immersion period beyond ~2.5 min within a 15 min recovery period, does not induce additional ergogenic benefits.

Immediately after each water immersion intervention there was a significant afterdrop (hypothermic undershoot) effect which was of a similar magnitude for both interventions (~0.4°C), that is caused by a rapid redistribution of blood from the cooled peripheral tissues to the core.[27] These afterdrop effects are consistent with previous similar studies.[4, 5, 14] The drop in T_{core} in the present study was accompanied by reductions in HR during the initial sprints post-recovery, possibly due to a decrease in thermoregulatory strain.[28] Nevertheless, it should be noted that due to this prolonged reduction in T_{core}, the total work done and power output achieved in the initial sprints performed immediately after both CWI interventions were indeed lower (albeit non-significant) than for the passive condition, however, particularly from sprint 8 until the end of the protocol TW and PP were always numerically higher in CWI-2.5 and CWI-5 compared with the passive rest condition (results not shown). This suggests that once muscles are properly warmed up, the increased heat storage capacity induced by the lower T_{core} response likely contributed to the overall beneficial effects in subsequent sprint performance.[29] It is unlikely that he afterdrop effect put participants at greater risk for muscular strain given the relatively small reduction in T_{core} and the fact that participants carried out a post-immersion warm up bout.

Since participants in the CWI interventions are aware of the intervention, we cannot exclude the possibility that the beneficial performance effects observed in the present study were due to a placebo effect. Gastrointestinal temperature demonstrates a slower response time to an increase in temperature relative to esophageal temperature.[30] Despite this, in the present study the thermal afterdrop occurred relatively fast (i.e. it reached the lowest T_{core} value in the vast majority of participants within the first ~5 min post-recovery), and thus, the likely slower dynamic change in temperature using gastrointestinal relative to esophageal temperature has a small influence in the interpretation of the present findings. Ingestion of large amounts of fluids reduces gastrointestinal temperature.[31] To minimize this effect, participants in the present study were allowed to drink only a minimal amount of water (<50ml). Future studies should employ treadmill running or field-based running tests as they are more ecologically valid for team-sport situations, and should incorporate measurements of skin temperature as well as fluid/body mass losses between trials.

5. Conclusion

In conclusion, the present study demonstrated that compared with a passive rest condition, a brief (2.5 to 5 min) post-exercise cold water immersion at 8°C significantly ameliorated the reductions in the total work completed and average peak power achieved in the second half of an intermittent sprint test protocol designed to mimic the playing requirements of a team sport match in normothermic laboratory conditions. These ergogenic benefits were likely mediated, at least in part, by reductions in T_{core} and cardiovascular strain. The ergogenic effects of alternative, and perhaps more practical approaches, such as cold water showers, should also be explored in future studies.

Practical implications

- A brief (2.5 to 5 min) cold water immersion, employed within a 15 min recovery period, ameliorates the decrements in subsequent intermittent sprint performance that mimics activity patterns of team sports.

- An immersion period beyond ~2.5 min does not induce additional ergogenic benefits
- These findings are encouraging to support the use of cold water immersion during half-time intervals in normothermic ambient conditions.

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Figure legends

Figure 1 Mean (±SD) total work done (A), mean power (B), peak power (C) and $\dot{V}O_2$ (D) during the intermittent sprint test in the first and second halves for the three experimental conditions. *Significantly different from first half ($P < 0.05$).

Figure 2 Mean (±SD) core temperature (A) and heart rate (B) responses at different time points during the experimental trial for the three conditions. * CWI-5 significantly different from passive rest ($P < 0.05$); † CWI-2.5 significantly different from passive rest ($P < 0.05$); ‡ CWI-2.5 significantly different from CWI-5 ($P < 0.05$).

Supplementary material

Schematic of the first half of the intermittent sprint test. Each 40-min half was separated into 2-min blocks (8-s ‘all-out’ sprint, 100 s of active recovery, and 12 s of passive rest). On two occasions (after sprints 8 and 16) participants performed 5 x 6-s sprints separated by 14 s of active recovery.

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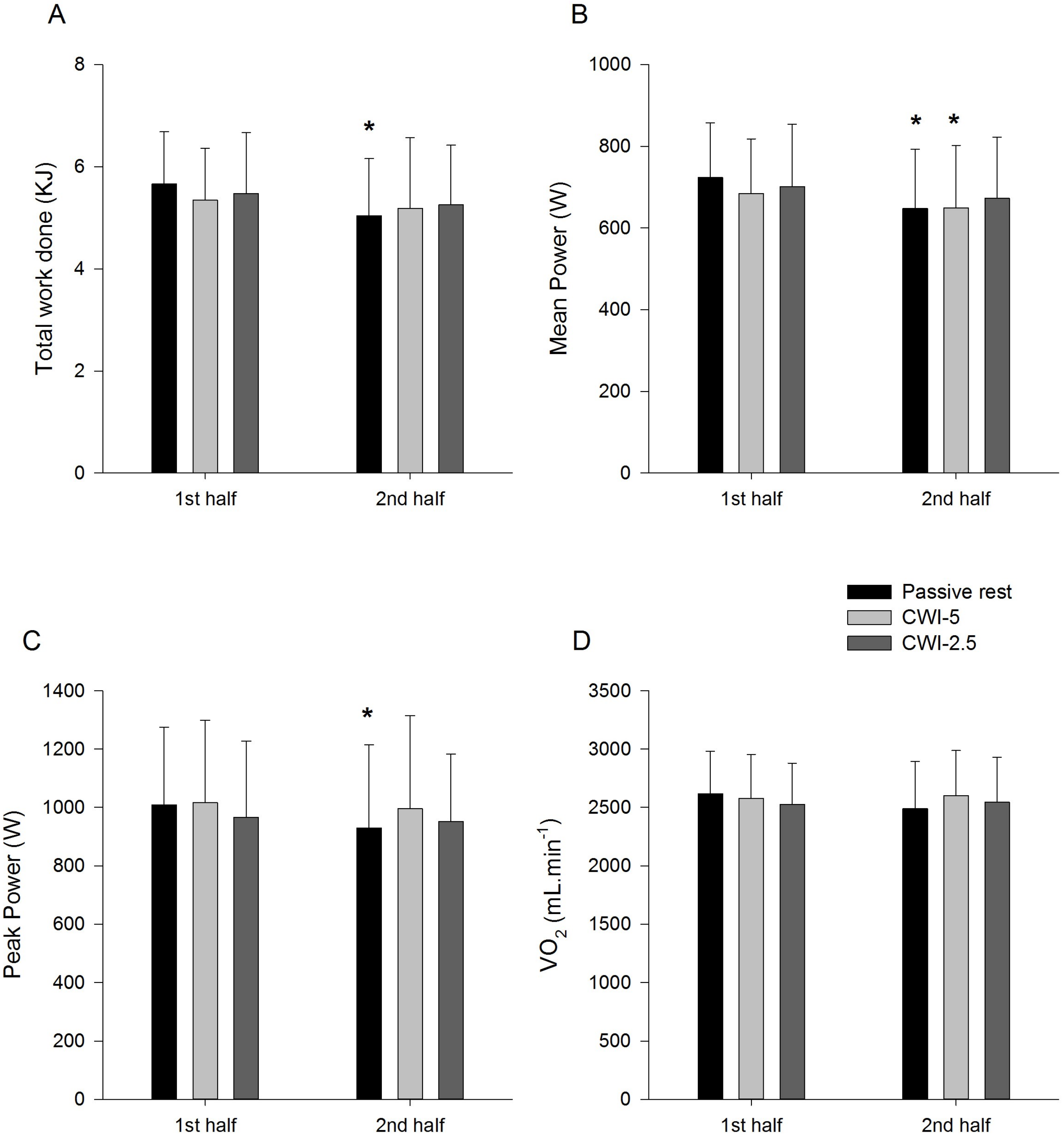
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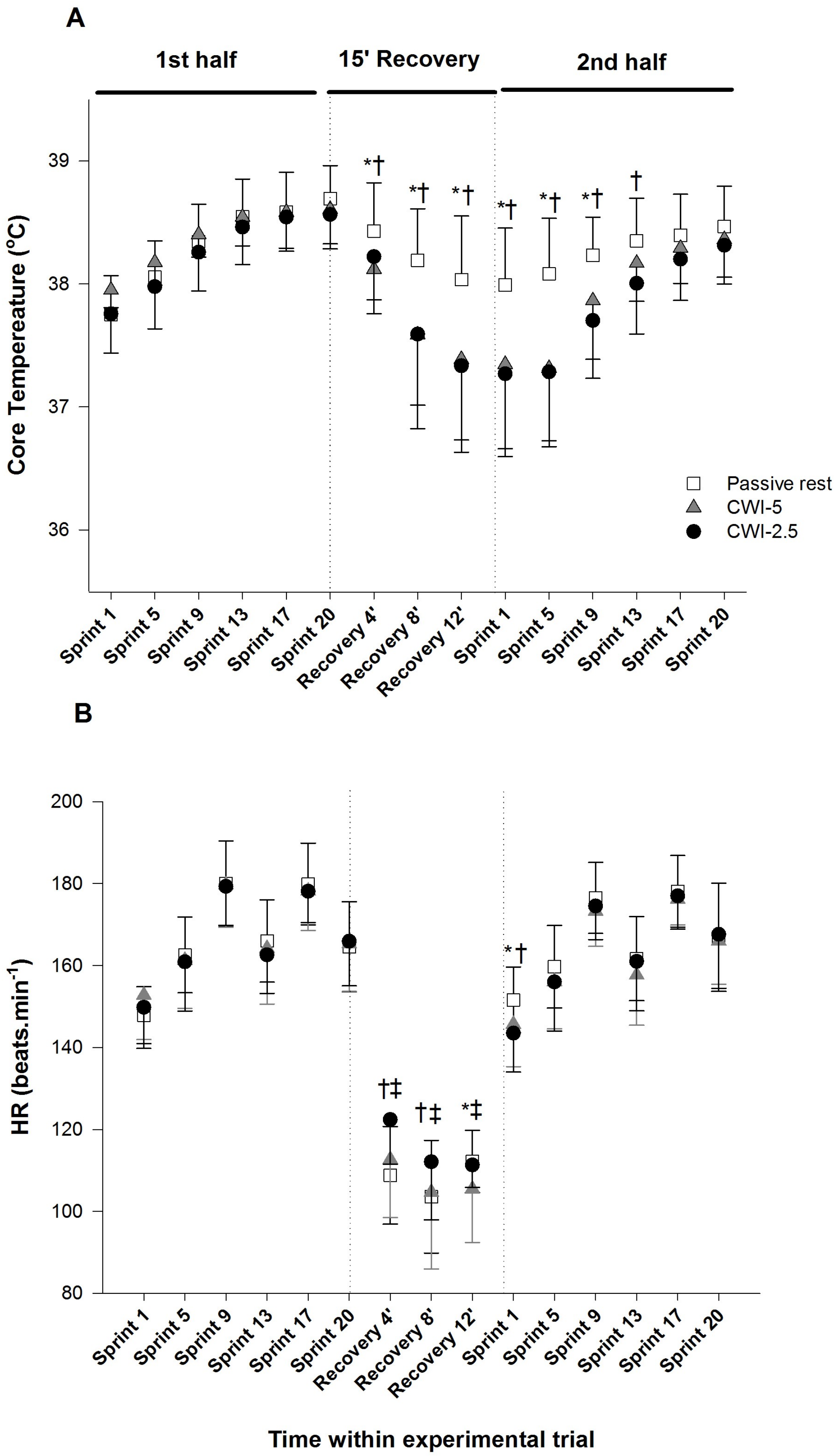
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Time within experimental trial