



The effects of cold water immersion on the amount and quality of sleep obtained by elite cyclists during a simulated hill climbing tour

Michele Lastella¹ · Gregory D. Roach¹ · Shona L. Halson² · Charli Sargent¹

Received: 6 September 2018 / Accepted: 16 December 2018 / Published online: 2 January 2019
© Springer-Verlag Italia S.r.l., part of Springer Nature 2019

Abstract

Background The aim of the present study was to examine the effects of cold water immersion on the amount and quality of sleep obtained by elite cyclists during a simulated hill climbing tour.

Methods Ten male professional cyclists (age 21.1 ± 1.7 years) from the Australian Institute of Sport were monitored for eight consecutive nights during a simulated hill climbing tour. The experiment employed a randomised cross over design. Cyclists followed a simulated hill climbing tour consisting of two 3-day sessions (140–190 km per day) separated by 2 days where ~60 km recovery rides were performed. During the first 3 days of simulated competition, five participants underwent a hydrotherapy recovery session (cold water immersion; 11–12 °C for 10 min), while the remaining five participants completed a placebo (ultrasound turned off; 10 min) recovery session. Recovery sessions were completed within 30 min of the conclusion of each competitive session (hh:mm; 13:00–14:00). After 2 days of recovery, participants reversed conditions.

Results Paired samples *t* tests revealed no differences in the amount and quality of sleep obtained by elite cyclists between conditions. Sleep latency was shorter in the cold water immersion condition compared to the placebo condition ($p = 0.03$). With the exception of sleep latency, sleep/wake behaviours were similar between the cold water immersion and placebo conditions ($p > 0.05$).

Conclusion Cold water immersion did not affect the sleep of elite athletes within this sample. If coaching staff are using cold water immersion as a post-exercise recovery strategy, they may continue to utilise this form of recovery without any impact on their athlete sleep.

Keywords Recovery · Actigraphy · Athletes · Cycling · Sport · Behaviour

Introduction

Elite cyclists are frequently exposed to high training loads with minimal time for recovery [1]. Establishing the balance between training and adequate recovery is considered a critical factor for achieving optimal performance [2]. The importance of recovery towards performance is evident in the number of recovery strategies employed within athletic settings, some of which include cold water immersion [3], compression garments [4], massage [5], low-intensity

exercise, and stretching [6]. Despite the introduction of numerous recovery strategies, cold water immersion is one of the most widely used and seems to benefit subsequent athletic performance [7, 8].

Studies examining the physiological effects of cold water immersion in competitive cyclists have shown significant decreases in core body temperature [3, 7]. In healthy adults, the rapid decline in core body temperature helps sleep onset and promotes deep sleep [9, 10]. This is relevant for the recovery of athletes as the body releases growth hormones that stimulate the protein synthesis necessary for muscle repair during deep sleep [11–13]. Unfortunately, only a few studies have examined the effects cold water immersion on the sleep of elite athletes [14, 15]. Available studies have found no clinically significant changes in sleep quality and quantity [14, 15]. This is in contrast to the anecdotal reports of athletes experiencing enhanced sleep quality and quantity following cold water immersion. The underlying mechanism

✉ Michele Lastella
m.lastella@cqu.edu.au

¹ Appleton Institute for Behavioural Science, Central Queensland University, 44 Greenhill Road, Wayville, Adelaide 5034, Australia

² School of Behavioural and Health Sciences, Australian Catholic University, Melbourne, Australia

behind enhanced sleep following cold water immersion is related to the association between core body temperature and melatonin secretion [16]. The circadian rhythm of melatonin secretion is inversely proportional to the normal core body temperature; therefore, the decline of core body temperature is strongly related to sleep propensity and sleep onset [17].

An alternative explanation that may lend support to the notion that cold water immersion leads to a better sleep quality and quantity is related to proprioceptive reduction of muscle soreness that occurs following cold water immersion [18, 19]. For example, feelings of heaviness, muscle fatigue, and discomfort have been frequently reported to have a negative effect on sleep quality, and thus, the reduction of such perceptible feelings as shown following cold water immersion may improve sleep quality and quantity [20, 21].

Given the widespread use of cold water immersion in athletic settings [22, 23], it is important to investigate if cold water immersion positively or negatively affects sleep following intensified training. Therefore, the aim of this study was to examine the effects of cold water immersion on the sleep of elite cyclists during a simulated hill climbing tour.

Materials and methods

Participants

Ten male professional cyclists (age 21.1 ± 1.7 years; body mass 67.5 ± 5.6 kg; VO_2 peak 68 ± 26 ml/kg/min) volunteered to participate in the study. All participants were competitive at a national level. Cyclists did not report any sleep disorders prior to participation in the study and none were detected during the study. The study was approved by the human research ethics committee of the Australian Institute of Sport Human Research Ethics Committee (20100802). All participants provided written informed consent.

Design

The experiment employed a randomised cross over design and was part of a larger study. Athletes followed a simulated hill climbing tour consisting of two 3-day sessions

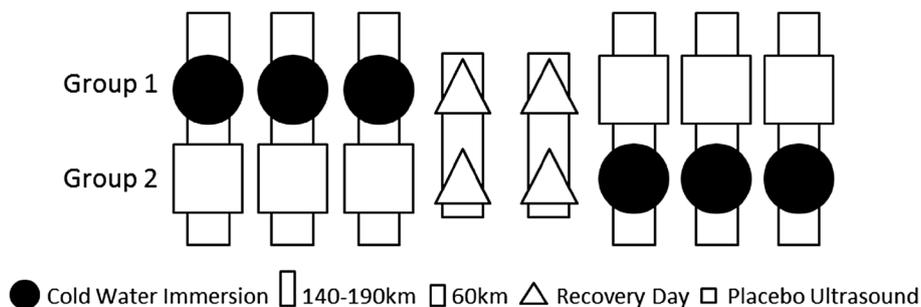
(mean \pm SD; $173.6 \text{ km} \pm 14.5 \text{ km}$ per day) separated by 2 days where $\sim 60 \text{ km}$ light recovery rides were performed. Before each session, participants completed a 30-min cycling warm up at 08:00 h. All rides involved riding outside on variable terrain (e.g., climbing and flats) and were performed in a simulated competition format to accurately represent competition. The duration and distance covered were recorded using a Garmin Cycling Computer [15]. All rides were supervised by a follow vehicle and a coach to ensure compliance. Participants used their own bicycles for the duration of the study. During the first 3 days of simulated competition, five participants underwent a hydrotherapy recovery session (cold water immersion), while the remaining five participants completed a placebo (ultrasound turned off) recovery session. After 2 days of recovery, participants reversed conditions (Fig. 1). The average (mean \pm SD) weather temperature recorded throughout the data collection was $26^\circ\text{C} \pm 1^\circ\text{C}$, min $18^\circ\text{C} \pm 2^\circ\text{C}$, and max $33 \pm 2^\circ\text{C}$.

Each supervised cold water immersion recovery session required participants to submerge their body in a plunge pool (excluding head and neck) set at $11\text{--}12^\circ\text{C}$ for 10 min. This was completed within 30 min of the conclusion of each competitive session. Each placebo condition required participants to receive a sham ultrasound treatment on their legs (ultrasound machine not turned on) by a qualified physiotherapist for 10 min within 30 min after each competitive session. All recovery sessions were completed within 30 min of the conclusion of each competitive session (hh:mm: 13:00–14:00).

Sleep/wake assessment

Sleep/wake behaviour was monitored using self-report sleep diaries and wrist activity monitors (Philips Respironics, Bend, OR, USA). Participants were asked to record their bedtime and pre-sleep fatigue prior to a night-time sleep period and their get-up time, and sleep quality as soon as practicable after waking. Each participant slept in a private bedroom, but shared bathroom and living-room facilities. The participants were instructed not to remove their activity monitor except when showering, swimming, or submersion. Data derived from the sleep diaries and wrist activity

Fig. 1 Study protocol illustrating the cross over design between the cold water immersion and placebo ultrasound conditions



monitors were used to determine participants' amount and quality of sleep [24]. All time was scored as wake unless: (1) the sleep diary indicated that the participant was lying down attempting to sleep and (2) the activity counts derived from the activity monitor were sufficiently low to indicate that the participant was immobile. Once these conditions were met simultaneously, time was scored as sleep. This scoring process was conducted using Phillips Respironics' Actiwatch algorithm with sensitivity at 'medium' [25, 26]. This algorithm has recently been used to quantify the sleep/wake behaviour in elite athletes [27–30]. The following sleep variables were derived from the activity monitor and sleep diary data:

- *Bedtime (hh:mm)* the self-reported time at which a participant went to bed to attempt to sleep.
- *Get-up time (hh:mm)* the self-reported time at which a participant got out of bed and stopped attempting to sleep.
- *Sleep latency (min)* the period of time between bedtime and sleep onset time.
- *Time in bed (h)* the amount of time spent in bed attempting to sleep between bedtime and get-up time.
- *Total sleep time (h)* the total amount of sleep obtained during a sleep period.
- *Sleep efficiency (%)* the percentage of time in bed that was spent asleep.
- *Subjective sleep quality* the participants' self-rating of sleep quality on a five-point Likert scale of 1 (very poor)–5 (very good).

Data analysis

Paired samples *t* tests were conducted to determine the impact of recovery strategy (cold water immersion versus placebo ultrasound) on the amount and quality of sleep obtained by elite cyclists during a simulated hill climbing tour. The dependent variables were sleep onset time, sleep offset time, sleep latency, time in bed, total sleep time, sleep efficiency, and subjective sleep quality. Mean differences and effect sizes with 95% confidence limits (CL) were calculated to quantify the magnitude of difference in all pairwise comparisons and were interpreted using Cohen's *d* values: trivial (0–0.19), small (≤ 0.20 –0.49), medium (≤ 0.50 –0.79), and large (≥ 0.80) [31]. To make inferences about the true value of an effect, the uncertainty in the effect was expressed as 95% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds of small positive or negative effects [32]. The Shapiro–Wilk test for equality supported the normality for all outcome variables. Data were analysed using SPSS (v23.0) statistical software. The statistical significance was set at $p < 0.05$.

Results

On average, cyclists went to bed at $22:03 \pm 00:03$, woke up at $05:50 \pm 00:08$, spent 7.6 ± 0.5 h in bed, and obtained 6.3 ± 0.5 h of sleep. Paired samples *t* tests revealed a significant difference in sleep latency between the cold water immersion compared to the placebo ultrasound condition (Table 1). Paired samples *t* tests revealed no differences for any other sleep variables (i.e., bedtime, get-up time, time in bed, total sleep time, sleep efficiency, and subjective sleep quality) between the cold water immersion and placebo ultrasound conditions (Table 1).

Discussion

The main finding of this study was that cold water immersion did not influence the amount or quality of sleep obtained by professional cyclists during a simulated hill climbing tour. It was revealed that sleep latency was shorter on the first night of the cold water immersion condition compared to the first night of placebo ultrasound condition. However, no differences were observed on the second and third night between conditions. It is plausible that the first day of cold water immersion may have been influenced by the initial proprioceptive reduction of muscle soreness, resulting in reduced muscle discomfort [15]. Irrespective of the condition employed, cyclists' obtained less than 6.5 h (i.e., 6.2–6.3 h) of sleep per night. When compared to other studies examining the sleep/wake behaviour of cyclists, the duration of sleep was similar. For example, Sargent et al. [29] and Lastella et al. [27] reported sleep durations in cyclists of 6.5 h and 6.7 h, respectively. Together, these data indicate that cyclists' obtain well below the general target of 8 h of sleep per night for adults [33]. Although a single night of sleep loss is unlikely to negatively affect psychological well-being and physiological performance negatively, the cumulative effect of losing 1.5–2 h per night may have a detrimental effect on psychological and physiological state, particularly during intensive training programmes and longer endurance competitions [34].

The simulated competition schedule employed in this study required cyclists to complete 140–190 km per day (i.e., 5–6.5 h of cycling) starting at 08:00 h. This type of schedule reduced the variability of bedtime (range 24–29 min) and get-up times (range 6–23 min) across cyclists. While it appears that cyclists' bed and wake up times were standardised, this was likely to be a result of the simulated competition schedule. This is reflective of athlete's schedules which are often dictated by their

Table 1 Sleep variables (mean \pm standard deviation) following cold water immersion and placebo ultrasound conditions

Characteristic	CWI 1 (n = 48)	Placebo 1 (n = 67)	Effect size (95% CL)	CWI 2 (n = 48)	Placebo 2 (n = 67)	Effect size (95% CL)	CWI 3 (n = 48)	Placebo 3 (n = 67)	Effect size (95% CL)
Bedtime (hh:mm)	21:59 \pm 00:21	22:10 \pm 01:30	-0.40 (-1.36 to 0.61)	22:15 \pm 00:52	22:07 \pm 0:24	0.21 (-0.86 to 0.125)	22:23 \pm 00:39	22:26 \pm 00:30	-0.09 (-1.01 to 0.84)
Get-up time (hh:mm)	05:28 \pm 01:02	07:41 \pm 01:01	0.14 (-0.85 to 1.11)	09:22 \pm 01:41	08:41 \pm 00:57	0.14 (-0.92 to 1.17)	10:01 \pm 01:40	08:31 \pm 01:01	0.48 (-0.46 to 1.41)
Sleep latency (min)	13.4 \pm 12.3	25.8 \pm 21.7	-0.71 (-1.67 to 0.34)*	15.9 \pm 15.6	19.14 \pm 17.5	-0.20 (-1.24 to 0.86)	13.0 \pm 14.7	17.0 \pm 16.7	-0.24 (-1.15 to 0.70)
Time in bed (h)	7.9 \pm 0.3	7.7 \pm 0.4	0.44 (-0.58 to 1.40)	7.6 \pm 0.3	7.7 \pm 0.4	-0.16 (-1.20 to 0.90)	7.4 \pm 2.2	5.1 \pm 1.2	0.13 (-0.80 to 1.05)
Total sleep time (h)	6.6 \pm 0.4	6.2 \pm 0.3	1.16 (0.05–2.15)	6.2 \pm 0.6	6.2 \pm 0.5	0.05 (-1.00 to 1.09)	6.3 \pm 0.4	6.2 \pm 0.5	0.07 (-0.85 to 0.99)
Sleep efficiency (%)	88.4 \pm 2.1	87.3 \pm 2.9	0.43 (-0.58 to 1.40)	87.0 \pm 3.9	87.7 \pm 3.2	0.03 (-1.02 to 1.07)	88.0 \pm 3.2	88.0 \pm 1.7	0.01 (-0.92 to 0.92)
Subjective sleep quality (units)	2.9 \pm 1.2	2.7 \pm 1.2	0.17 (-0.89 to 1.20)	3.0 \pm 1.4	3.4 \pm 1.5	-0.30 (-1.33 to 0.54)	2.3 \pm 1.2	2.8 \pm 1.2	-0.41 (-1.33-0.54)

Bolded effect size = medium-to-large effect. Non-bolded effect sizes were interpreted as unclear

* $p < 0.05$

training and competition. The influence that training and competition schedule on the sleep/wake behaviour of elite athletes is well documented [28, 35, 36]. Sargent et al. [28] reported that on nights that preceding early morning training, athletes' bed and wake up times were significantly earlier when compared to nights that preceded rest days. Data from Sargent et al. [28, 29] suggest that modifying sleep/wake behaviours and potentially the timing of training may enable athletes to obtain more sleep.

While cold water immersion has been reported to be an effective for perceptual muscle recovery [15], the recent developments indicate that extending the amount of sleep athletes obtain can also improve psychological well-being and performance [37]. Mah et al. [37] found that, after extending sleep by 1.8 h from a baseline of 6.7 h of sleep per night over a 7-week period, basketball players showed significant decreases in fatigue and sleepiness. In addition, athletes showed significant improvements in performance assessments such as sprint times and free-throw shooting accuracy. These data support the notion that sleep is critical for the post-exercise recovery process and athletic performance [38–40].

It is important to acknowledge the limitations of this study when interpreting the results. The timing of cold water immersion was set within 30 min of the conclusion of each competitive session which may have had minimal influence of the reduction in core body temperature in relation to sleep onset. Indeed, this limitation may lend support to the perceptual benefits of cold water immersion toward muscle recovery and relaxation [15]. Furthermore, the lack of control over cyclists' diet and room temperature may have resulted in individual differences. Future studies should ensure that diet, sleeping environments, and room temperature are controlled to appropriately control the effect of cold water immersion which has on sleep.

Conclusion

The findings from the present study are similar to the previous research, indicating that cold water immersion does not influence the sleep of elite athletes [14, 15]. However, future investigations should examine core body temperature constantly throughout the sleep period to determine whether any differences lead up to sleep onset and during the night occurs. A consideration should also be given to the timing of training and cold water immersion as this may influence the rate core body temperature decline following immersion [14]. At present, there is no evidence to indicate that cold water immersion causes any disruption to the sleep of elite athletes. To this end, if coaching staff are using cold water immersion as a post-exercise recovery

strategy, they may continue to utilise this form of recovery without any impact on their athlete sleep.

Acknowledgements The authors would like to thank all the participants who took part in the study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the human research ethics committee of the Australian Institute of Sport Human Research Ethics Committee (20100802).

Informed consent All participants provided written informed consent.

References

- Lamberts RP, Swart J, Capostagno B et al (2010) Heart rate recovery as a guide to monitor fatigue and predict changes in performance parameters. *Scand J Med Sci Sports* 20(3):449–457
- Halson SL, Jeukendrup AE (2004) Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Med* 34(14):967–981
- Halson SL, Quod MJ, Martin DT et al (2008) Physiological responses to cold water immersion following cycling in the heat. *Int J Sports Physiol Perform* 3(3):331–346
- Driller MW, Halson SL (2013) The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. *J Sci Cycl* 2(1):45–50
- Lane KN, Wenger H (2004) Effect of selected recovery conditions on performance of repeated bouts of intermittent cycling separated by 24 hours. *J Strength Cond Res* 18(4):855–860
- Cortis C, Tessitore A, D'Artibale E et al (2010) Effects of post-exercise recovery interventions on physiological, psychological, and performance parameters. *Int J Sports Med* 31(5):327–335
- Vaile J, Halson S, Gill N et al (2008) Effect of hydrotherapy on recovery from fatigue. *Int J Sports Med* 29(7):539–544
- Rowell GJ, Coutts AJ, Reaburn P et al (2009) Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *J Sports Sci* 27(6):565–573
- Kräuchi K (2002) How is the circadian rhythm of core body temperature regulated? *Clin Auton Res* 12(3):147–149
- Kräuchi K (2007) The human sleep–wake cycle reconsidered from a thermoregulatory point of view. *Physiol Behav* 90(2):236–245
- Nedelcheva AV, Kilkus JM, Imperial J et al (2010) Insufficient sleep undermines dietary efforts to reduce adiposity. *Ann Intern Med* 153(7):435–441
- Dattilo M, Antunes H, Medeiros A et al (2011) Sleep and muscle recovery: endocrinological and molecular basis for a new and promising hypothesis. *Med Hypotheses* 77(2):220–222
- Venter RE (2012) Role of sleep in performance and recovery of athletes: a review article. *S Afr J Res Sport Phys Educ Recreat* 34(1):167–184
- Robey E, Dawson B, Halson S et al (2013) Effect of evening postexercise cold water immersion on subsequent sleep. *Med Sci Sports Exerc* 45(7):1394–1402

15. Halson SL, Bartram J, West N et al (2014) Does hydrotherapy help or hinder adaptation to training in competitive cyclists. *Med Sci Sports Exerc* 46(8):1631–1639
16. Wright KP, McHill AW, Birks BR et al (2013) Entrainment of the human circadian clock to the natural light-dark cycle. *Curr Biol* 23(16):1554–1558
17. Lack LC, Wright HR (2007) Chronobiology of sleep in humans. *Cell Mol Life Sci* 64(10):1205–1215
18. Roberts LA, Nosaka K, Coombes JS et al (2014) Cold water immersion enhances recovery of submaximal muscle function after resistance exercise. *Am J Physiol Regul Integr Comp Physiol* 307(8):R998–R1008
19. Ascensao A, Leite M, Rebelo AN et al (2011) Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *J Sports Sci* 29(3):217–225
20. Matos NF, Winsley RJ, Williams CA (2011) Prevalence of non-functional overreaching/overtraining in young English athletes. *Med Sci Sports Exerc* 43(7):1287–1294
21. Hausswirth C, Louis J, Aubry A et al (2014) Evidence of disturbed sleep patterns and increased illness in functionally overreached endurance athletes. *Med Sci Sports Exerc* 46(5):1036–1045
22. Wilcock IM, Cronin JB, Hing WA (2006) Water immersion: does it enhance recovery from exercise? *Int J Sports Physiol Perform* 1(3):195
23. Cochrane DJ (2004) Alternating hot and cold water immersion for athlete recovery: a review. *Phys Ther Sport* 5(1):26–32
24. Sargent C, Lastella M, Halson SL et al (2015) The validity of activity monitors for measuring sleep in elite athletes. *J Sci Med Sport* 19(10):848–853
25. Weiss AR, Johnson NL, Berger NA et al (2010) Validity of activity-based devices to estimate sleep. *J Clin Sleep Med* 6(4):336–342
26. Kosmadopoulos A, Sargent C, Darwent D et al (2014) Alternatives to polysomnography (PSG): a validation of wrist actigraphy and a partial-PSG system. *Behav Res Methods* 46(4):1032–1041
27. Lastella M, Roach GD, Halson SL et al (2015) Sleep/wake behaviours of elite athletes from individual and team sports. *Eur J Sport Sci* 15(2):1–7
28. Sargent C, Halson S, Roach GD (2014) Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *Eur J Sport Sci* 14(Suppl 1):S310–S315
29. Sargent C, Lastella M, Halson SL et al (2014) The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiol Int* 31(10):1160–1168
30. Roach GD, Schmidt WF, Aughey RJ et al (2013) The sleep of elite athletes at sea level and high altitude: a comparison of sea-level natives and high-altitude natives (ISA3600). *Br J Sports Med* 47(S1):i114–i120
31. Winter EM, Abt GA, Nevill AM (2014) Metrics of meaningfulness as opposed to sleights of significance. *J Sports Sci* 32(10):901–902
32. Hopkins W, Marshall S, Batterham A, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41(1):3
33. Belenky G, Wesensten NJ, Thorne DR et al (2003) Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res* 12(1):1–12
34. Blumert P, Crum AJ, Ernstrung M et al (2007) The acute effects of twenty-four hours of sleep loss on the performance of national-caliber male collegiate weightlifters. *J Strength Cond R* 21(4):1146–1154
35. Lastella M, Roach GD, Halson SL et al (2014) Sleep/wake behaviour of endurance cyclists before and during competition. *J Sports Sci* 33(3):293–299
36. Leger D, Elbaz M, Raffray T et al (2008) Sleep management and the performance of eight sailors in the Tour de France a la voile yacht race. *J Sport Sci* 26(1):21–28
37. Mah CD, Mah KE, Kezirian EJ et al (2011) The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 34(7):943
38. Samuels C (2008) Sleep, recovery, and performance: the new frontier in high-performance athletics. *Neurol Clin* 26(1):169–180
39. Nedelec M, Aloulou A, Duforez F, Meyer T, Dupont G (2018) The variability of sleep among elite athletes. *Sports Med Open* 4(1):34
40. Vitale JA, Banfi G, Galbiati A, Ferini-Strambi L, Torre AL (2018) Effect of night-game on actigraphy-based sleep quality and perceived recovery in top-level volleyball athletes. *Int J Sports Physiol Perform*. <https://doi.org/10.1123/ijspp.2018-0194>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.