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3-min whole body cryotherapy/cryostimulation after training in the evening improves sleep quality in physically active men

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Abstract
Exercise training during evening may disturb sleep patterns and hinder recovery process. The present study aimed to examine the effect of whole body cryotherapy (WBC) exposure after training in the evening on sleep quality and night heart rate variability (HRV). A total of 22 physically active men were randomized to undergo either WBC (3-min at −40°C, wind speed of 2.3 m s^{-1}) or passive recovery (control) following an evening training consisting of 25 min of continuous running at 65% of the maximal aerobic speed (MAS) followed by intermittent running at 85% of the MAS. Each night following the training, the number of movements and HRV during sleeping time were recorded. The next morning, subjective sleep quality and perceived pain were assessed using Spiegel questionnaire and a visual analogue scale, respectively. The number of movements during the night following WBC was significantly reduced ($p < 0.05$) compared with the control condition. Subjective sleep quality following WBC was significantly better than the control group ($p < 0.05$). During the estimated slow-wave sleep (SWS), the high frequency power (HF) was higher in the WBC group than the control group ($p < 0.05$), and the low frequency power (LF) and the LF/HF ratio were lower than the control group ($p < 0.05$). Pain was significantly reduced following WBC compared to the control ($p < 0.01$). In conclusion, the use of 3-min WBC after training in the evening improves subjective and objective sleep quality in physically active subjects, which may be due to greater pain relief and improved parasympathetic nervous activity during the SWS period.

Keywords: *Cryotherapy, cold exposure, sleep, heart rate variability, parasympathetic system, pain*

Highlights

- The use of 3-min whole-body cryotherapy/cryostimulation after evening training improves the subjective sleep qualityand the morning form state.
- The use of 3-min whole-body cryotherapy/cryostimulation after evening training improves the objective sleep quality by reducing the number of movements during sleep.
- The use of 3-min whole-body cryotherapy/cryostimulation after evening training enhances the pain relief and improvesparasympathetic nervous activity during the deep sleep (slow wave sleep).

Introduction

Adequate sleep is essential for maintaining high levels of mental and physical performance in professional athletes (Chennaoui, Arnal, Sauvet, & Léger, 2015). Sleep is considered as an important recovery process due to its physiological restorative effects for reinstating molecular homeostasis, synaptic plasticity and cellular maintenance (Fullagar et al., 2015). However, high-level athletes often travel or train in the evening and at night due to busy schedules, which can easily disrupt normal sleep-wake cycles and may even cause poor sleep quality. It is assumed that performing physical exercise less than 4 h before bedtime induces sleep disturbances (Chennaoui et al., 2015). In professional soccer players, late-night exercise induces a greater

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number of sleep disturbances compared to daylight exercise (Meyer, Wegmann, Poppendieck, & Fullagar, 2014). Similarly, 53% of elite Australian athletes (*n* = 283) reported increased sleep disturbances after a night match or training (Juliff, Halson, & Peiffer, 2015). Furthermore, high intensity exercise conducted in the evening for judo competitors results in an increased number of awakenings and delayed sleep onset, and a recent review/ meta-analysis expressed that intense exercise very close to bedtime might impaired sleep-onset latency, total sleep time and sleep efficiency (Stutz, Eiholzer, & Spengler, 2018). Disturbed sleep following late-night exercise is explained either by increased arousal and prolonged wakefulness induced by physical exercise (Meyer et al., 2014) or an increase in perceived pain induced by the physical exercise (Fullagar et al., 2015). Inadequate sleep quality and quantity likely hinders psychological and physical recovery and limits training adaptations by impeding muscle protein accumulation (Fullagar et al., 2015). From a psychological point of view, sleep loss disrupts mood, confidence and perceptual awareness. In addition, athletes with sleep loss are more likely to suffer from exercise-related injuries (Chennaoui et al., 2015). A decrease in proprioception, postural control (Dattilo et al., 2011; Gosselin et al., 2009) and reaction time (Martin, 1981) could explain such feature. Indeed, maintaining good sleep quality to facilitate the recovery process has been a concern for athletes over the last decade. In this context, several studies have been conducted to evaluate the effect of slightly decreasing the body temperature on sleep quality (Bouzigon, Ravier, Dugue, & Grappe, 2014; Haddad, Parouty, & Buchheit, 2012; Schaal et al., 2015). It has been reported that cold water immersion improves sleep quality following daily training (Haddad et al., 2012) and daily training in the heat (Skein, Wingfield, Gale, Washington, & Minett, 2018). It was recently shown that cryotherapy exposure, which consists of short exposure to very cold air (from −110°C to −195°C) in special rooms (cryo chambers or cryo cabins) after exercise promotes good sleep quality both in elite synchronized female swimmers (during a period of intense training associated with symptoms of overtraining; the swimmers experienced 3-min exposure at −110°C, daily for 14 days) and in professional basketball players (the players experienced a single 3-min exposure at −130°C) (Bouzigon et al., 2014; Schaal et al., 2015).

Cryotherapy/cryostimulation is commonly used for analgesic and anti-inflammatory purposes (Dupuy, Douzi, Theurot, Bosquet, & Dugué, 2018). The effects of cryostimulation in the decrease in body temperature could have an impact on sleep onset latency, as well as a decrease in skin temperature may have an analgesic effect and lower delayed onset of muscle soreness facilitating therefore a better quality of sleep. Cryo stimulus/stimuli may also have the power to readjust hormonal circadian rhythm and biological clock after a disturbance induced by high-intensity exercise close to bedtime. Nevertheless, the effect of cold exposure in the evening and quite near bedtime on sleep quality has not been investigated.

Therefore, it is unclear whether whole body cryotherapy can mitigate sleep disturbances resulting from evening exercise. Also, autonomic nervous activity has not been investigated during sleep following evening cryotherapy exposure. Nevertheless, there are several investigations reporting an increase of parasympathetic activity from 5 to 20 min following cold exposure (Hausswirth et al., 2013; Schaal et al., 2013). Heart rate changes during sleep are related to sleep stage, awakenings, and body movements (Johns, Thornton, & Doré, 1976). Also, it was recognized that parasympathetic function, quantified by heart rate variability indices, is strongly correlated with sleep quality (Schaal et al., 2013). As shown in a previous study, poor sleep quality was associated with a disturbance in heart rate variability (HRV) (Schaal et al., 2013). Sleep is characterized by large variations in HRV signals that decrease in non-REM (*Rapid Eye Movement*) sleep and increase in REM sleep (Stein & Pu, 2012). Previous studies (Brandenberger, Buchheit, Ehrhart, Simon, & Piquard, 2005; Buchheit, Simon, Piquard, Ehrhart, & Brandenberger, 2004) used HRV analyses, particularly in slow wave sleep episodes (SWS) in which there are fewer body movements, decreased arousal and a more regular respiratory pattern (Brandenberger et al., 2005). We assumed that a single exposure to whole body cryotherapy improves sleep quality after evening training and stimulates the reactivation of parasympathetic nervous activity. To verify this hypothesis, we examined the impact of 3-min whole body cryotherapy exposure on subjective and objective sleep quality and night HRV analysis following a standardized training session in physically active men.

Methods

Subjects

Twenty-two physically active, regularly training (at least 3 sessions per week, with sessions lasting at least for 1 h) and healthy men (age: 28.5 ± 7.3 years; weight: 71.7 ± 12.4 kg; height: 176.1 ± 6.1 cm; maximal aerobic speed (MAS): 17.2 ± 1.3 km/h) participated in the study. The participants were free of injury and illnesses, including sleep-related issues. They provided their written informed consent, which conformed to the code of ethics of the Declaration of Helsinki. The study was accepted by the local ethics committee. Participants refrained from heavy exercise for one day before the experiment, and coffee and alcohol were forbidden 24 h before and after the experiment. They were instructed not to perform any recovery procedure, such as massage or the use of compression garments, other than cryotherapy. As this investigation was a free-living investigation, the volunteers were instructed to keep their regular sleeping habits and to behave as similarly as possible on both conditions (sleeping habits, number of hours spent in bed, the level of light).

Experimental design

The experiment was held for two weeks. Each session occurred once per week on the same weekday and at the same time during the day (starting at 7 pm). Subjects undertook a standardized training session for 55 min. Then, each subject was assigned to a 3-min whole-body cryotherapy session using a recently described chamber (AuroreConcept®, Noisels, France) (Bouzigon et al., 2017) or 3-min passive recovery (participant were seated) in a random order. The randomization was performed using random permutation tables, generated by a computer algorithm. The night following the recovery (cryotherapy or passive), subjects wore accelerometers and heart rate monitors and recorded their bedtime and waking time in a logbook.

Training session

In both trials, the 55 min standardized training session was performed on a track at a temperature of 21–22°C. Each session consisted of a 5-min warm up, followed by a continuous exercise bout at 65% MAS for 25 min and an intermittent exercise bout consisting of 3 sets of 7 min at 85% MAS separated by 2 min of active recovery at 60% MAS. During the exercise bouts, all participants adjusted their speed and pace using a heart rate monitor (Polar V800 GPS, Finland) and were instructed to use the same speed in both trials. A checking was performed *a posteriori*. All of our subjects followed the instruction seriously and no speed differences were observed between the two sessions. There were no verbal encouragements nor other environmental factors that could affect arousal or sleep.

Recovery

Thirty minutes after the training session, subjects underwent either passive recovery or a 3-min cryotherapy session in a whole-body cryotherapy chamber with technology based on forced convection. This cryotherapy chamber was recently validated (Bouzigon et al., 2017), and it was shown that a 3-minute exposure induced the same skin temperature decreases as a 3-minute exposure between −60°C and −160°C in previous technologies (whole body or partial body cryotherapy chambers). Before exposure to cryotherapy, the blood pressure of each participant was measured at the left brachial artery using a sphygmomanometer (Omron Hem-7120, Omron Healthcare, Kyoto, Japan), and further assessments were performed to determine whether the subject had any contraindications to cryotherapy. The cryotherapy chamber was housed in a truck trailer and was composed of two chambers. First, the subject spent 30 s at −25°C in the first chamber and then 3 min in the main chamber at an exposure temperature of −40°C and with an average wind speed of $2.3\,\mathrm{m\,s^{-1}}$. During the exposure, the participant wore a surgical mask, a headband over his ears, underwear, socks, gloves and slippers.

Measurements

Skin temperatures. The main cryotherapy chamber was equipped with three thermal probes (CT LT, Optris, Berlin, Germany) to measure the skin temperature at the trunk, abdomen and upper thighs every 30 s during the exposure time.

Ratings of perceived fatigue and pain. Perceived pain and fatigue were assessed before and immediately after the exercise session, and the next morning (at the time of wake-up) using a visual analogue scale (VAS) ranging from 0 to 10 in which 0 corresponds to no pain or perceived fatigue and 10 represents pain or extreme fatigue (Costello, Algar, & Donnelly, 2012; Delextrat, Calleja-González, Hippocrate, & Clarke, 2013).

Heart rate variability assessment at night. Participants wore a heart rate monitor (Polar V800 GPS sport watch, Kempele, Finland) each night after exposure to cryotherapy or control session. They were asked to manually start recording the R-R intervals at bedtime and stop when they woke up. Data files were transferred to the computer using the Polar Flow application (Polar, Kempele, Finland) and were analysed using Kubios HRV software (version 2.1, 2012, MATLAB, Kuopio, Finland). For each subject, the night HRV was assessed during the entire sleep night, the first 4 h of sleep and the first 10-min stationary segment in the first slow-wave sleep (SWS) episode. As reported in previous study (Dupuy, Bherer, Audiffren, & Bosquet, 2013), the 4-hour analysis started 30 min after the recorded bedtime. The SWS episode was determined according to the method of Brandenberger et al. (2005). This segment was characterized by a stable HRV signal of 15 min with a round Poincaré plot and a low standard deviation of normal-to-normal intervals (SDNN). The Kubios HRV software provided a spectral analysis of low frequency (LF: 0.04–0.15 Hz) and high frequency (HF: 0.15–0.40 Hz) bands. Other time and frequency domain measures were obtained, such as the mean heart rate (HRmean), R-R interval (RRI), square root of the mean-squared differences of RRI (RMSSD), standard deviation (SD), total power (LF+ HF) and LF/HF power ratio.

Sleep quality assessment. Concerning the sleep quality assessment, each night after exposure to cryotherapy or passive recovery, all participants wore a wrist actigraph (WGT3X-BT monitor, Pensacola, USA) to record movements during sleep. Volunteers were asked to start the recording at bedtime and stop it when waking up the next morning. They were instructed to note in a logbook, the hour at which they went to bed and woke up. This actigraph is equipped with a receiver that captures movements on the horizontal, vertical and perpendicular axes. Data were sampled over a constant interval (epoch length of 60 s) and were extracted as the sum of the vector magnitude in counts/minute (calculated as the square root of the sum of the square of acceleration for each of the three axes) using actiLife software (version 6.11.0, Fort Walton Beach, FL, USA). The total sleep time was estimated from the provided bedtime and wake up time, and the movements during sleep were calculated for each participant as follows: total counts in each axis (x, y, and z)/total sleep time. For the sleep analysis, sleep efficiency [(actual sleep time/total sleep time)*100] was recorded. Also, subjective sleep quality was assessed using the Spiegel Sleep Quality Perception Questionnaire (Spiegel, 1984) completed in the morning following WBC exposure or passive recovery. Subjects answered six items, with scores that range from 0 to 5, for sleep time, quality of sleep, nocturnal awakenings, dreams and morning form state. The total score of the Spiegel questionnaire determined the subjective sleep quality.

Statistical analysis

All data were stored in an electronic database and analysed using specialized statistical software (Statistica 7.0, StatSoft, Tulsa, OK, USA). The Gaussian distribution was tested for each variable using the Shapiro–Wilk test. Paired t-test or non-parametric Wilcoxon test were used to assess the significant difference between the two conditions [cryotherapy (WBC) vs passive recovery (control)]. The results of the tests were considered significant at $p \leq 0.05$. The Hedges' g parameter (g) was used to assess the effect size of the changes and was then interpreted with the Cohen's criteria (Cohen, 1988) as a small ($0.2 < g \leq 0.5$), moderate ($0.5 < g \leq 0.8$), or large ($g > 0.8$) effect. The required sample size was calculated from our control data using G*Power version 3.1, according to Beck (Beck, 2013). Using an a priori repeated-measures design with a desired power (1-beta) set at 0.80, and an alpha risk of 0.05, twenty-one subjects represent a sufficient number of subjects to detect a significant difference. The results were expressed as the means with the standard deviation (SD).

Results

Sleep assessment using accelerometery

As shown in Figure 1, the number of movements detected in the three spatial axes during sleep was significantly lower the night following WBC compared to the control condition [X ($p < 0.01$), Y ($p < 0.01$); Z ($p < 0.01$)]. The effects size of these changes in the three spatial axes ranged from medium to large effects ($-0.6 < g < 0.8$). Sleep efficiency after WBC exposure (88.8 ± 6.3) was significantly higher than the control (84.3 ± 6.5) ($p < 0.05$).

Subjective assessment of sleep

The next morning after WBC exposure, Spiegel's total questionnaire score was significantly higher than after passive recovery (WBC: 20.9 ± 3.5 vs control: 23.1 ± 2.5, $p < 0.05$), which indicated improved subjective sleep quality. For the Spiegel questionnaire items, WBC induced a better morning form state ($p < 0.05$) than the control condition. The number of hours spent in bed was similar in both conditions (WBC: 414 min ± 43 min vs control: 434 min ± 57 min).

Heart rate variability during sleep

The time and frequency domain *analyses* of HRV during sleep are presented in Table I. There were no significant differences between the two conditions for any parameter of heart rate variability recorded during the entire night sleep and the first 4-hour period. In contrast, when HRV was assessed during the first 10-min SWS episode, we found that HF in the WBC condition was significantly higher than in

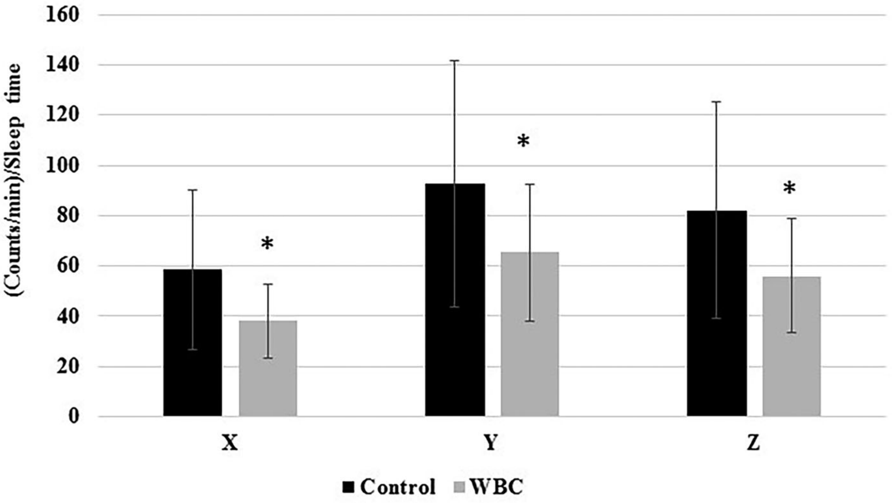

Figure 1. Counts per minute on the 3 movement axes (x: horizontal, y: vertical, and z: perpendicular) during sleep following whole body cryotherapy (WBC) or passive recovery (control). *Significant difference from the control at $p < 0.01$.

the control condition ($p < 0.05$), and the LF and LF/HF were significantly lower than in the control condition. We found no differences for other HRV analyses.

Skin temperature

The skin temperature was assessed in the main cryotherapy chamber at the end of the exposure, the skin temperature reached 15.0°C ± 1.7°C for the chest, 14.1°C ± 2.1°C for the abdomen and 12.4°C ± 1.6°C for the upper thighs.

Perceived fatigue and pain

After the exercise session, perceived fatigue and pain/muscle soreness were similar between the conditions (WBC: 6.3 ± 0.8 vs control: 5.2 ± 2.0, $p = 0.41$ concerning perceived fatigue; and WBC: 4.5 ± 1.8 vs control: 3.3 ± 2.0, $p = 0.59$ concerning pain/muscle soreness). When calculating the changes ((morning – evening score)/evening score) in the pain scores, we observed a significant larger decrease in the WBC (−58%) than in the control (−20%) condition ($p < 0.01$).

Discussion

The aim of this study was to investigate the impact of cold-exposure on sleep quality after an evening training. The main findings was that a single session of whole- body cryotherapy (3-min at −40°C; wind speed at 2.3 m s^{-1}) in the evening improves the

Table I. Averages of HRV analyses during the entire night sleep, the first four hours and the SWS episode after exposure to WBC or passive recovery (control).

	Whole Night		4 hours		SWS	
	Control	WBC	Control	WBC	Control	WBC
Mean RR (ms)	1152 ± 169	1103 ± 276	1126 ± 174	1059 ± 284	1112 ± 167	1137 ± 159
Mean HR (bpm)	53 ± 8	52 ± 8	54 ± 9	52 ± 12	55± 9	54 ± 8
SDNN (ms)	66 ± 17	72 ± 21	64 ± 27	66 ± 31	31 ± 10	39 ± 27
RMSSD (ms)	68 ± 28	75 ± 28	67 ± 40	67 ± 39	32 ± 16	44 ± 35
HF nu	38 ± 17	38 ± 12	42 ± 22	44 ± 21	34 ± 16	43 ± 17*
LF nu	61 ± 17	61 ± 12	58 ± 22	56 ± 21	66 ± 16	57 ± 17*
Total Power (ms^2)	4317 ± 1984	5202 ± 2964	5298 ± 4850	5242 ± 4900	954 ± 569	1932 ± 3263
LF/HF	2 ± 2.5	2 ± 0.9	3 ± 2	3 ± 2	3 ± 2	2 ± 2*
SD1 (ms)	48 ± 20	53 ± 20	47 ± 28	47 ± 28	22 ± 11	32 ± 25
SD2 (ms)	79 ± 17	85 ± 22	77 ± 28	79 ± 34	38 ± 10	44 ± 29

*Significantly different from control. Abbreviations: RR, R-R interval; HR, Heart rate; SDNN, standard deviation of normal-to-normal intervals; RMSSD, square root of the mean-squared difference of R-R interval; HF, high-frequency bands; LF, low frequency bands; Total power, LFnu + HFnu; LF/HF, LF/HF power ratio; SD1, standard deviation 1 of Poincaré plot; SD2, standard deviation 2 of Poincaré plot.

subjective and objective sleep quality, enhances the reactivation of parasympathetic activity and reduces the perceived pain 24 h after a standardized exercise regimen in physically active men.

Whole body cryotherapy exposure improved subjective sleep quality and enhanced the morning form state. These results were consistent with previous studies investigating the effect of cooling interventions (cold water immersion and cryotherapy) on subjective sleep quality (Bouzigon et al., 2014; Haddad et al., 2012). The beneficial effect of cryotherapy may be explained by a reduction of muscle soreness and improvement of well-being (Dupuy et al., 2018), which together lead to improved mood and subjective sleep quality. A previous study examined the relationship between sleep disturbances and perceived pain and reported that an increase in pain levels disrupts sleep by increasing arousal and triggering other neurobiological sequelae of stress (Lautenbacher, Kundermann, & Krieg, 2006). These authors suggested that greater pain relief enhances sleep quality and prevents its disturbance. Therefore, the observed pain reduction in the present study, likely due to the analgesic effect of cryotherapy, may promote better sleep quality and a less disturbed sleep pattern. However, a recent study (Skein et al., 2018) examining the effect of cold-water immersion on subjective and objective sleep quality reported improved subjective sleep quality without a change in the objective sleep characteristics, which may suggest a placebo effect for the cooling intervention.

The objective sleep quality was evaluated in the present study by assessing sleep efficiency and the number of movements during sleep on the three spatial axes. These variables were recorded with a wrist actigraph validated against laboratory polysomnography, and considered as an accurate tool for measuring and quantifying sleep (American Sleep Disorders Association, 1995). As shown in Figure 1, WBC exposure in the evening induced lower motor activity during sleep across the three spatial axes (horizontal, vertical, and perpendicular) than in the passive recovery. As reported in previous studies, the decrease of motor activity levels is indicative of deeper sleep (Middelkoop Huub, Hilten Bob, Kramer Cor, & Kamphuisen Hilbert, 1993; Miwa, Sasahara, & Matsui, 2007). A previous study investigating the effect of training load on sleep quality showed that high levels of motor activity were associated with an increased number of awakenings during sleep, whereas low levels of motor activity indicated deeper sleep (Middelkoop Huub, et al., 1993). Based on the frequency of rotational motion (roll-overs) during sleep, Miwa et al. (Miwa et al., 2007) proposed that recorded movements increased during light sleep and decreased during deep sleep. Accordingly, the observed lower motor activity levels following WBC exposure may be explained by deeper sleep and better sleep quality. Furthermore, sleep efficiency was improved following WBC exposure. This finding was consistent with a recent study (Schaal et al., 2015) conducted during an intense training period associated with a disruption in sleep quantity and quality. It was demonstrated that the daily use of WBC for two weeks improved swimmers' tolerance to training load by preserving sleep quantity and promoting the onset of sleepiness, particularly during periods of increased physical and psychological stress. Interestingly, the reduced body temperature may have potentially affected sleep by improving sleep propensity (O'Connor, Breus, & Youngstedt, 1998).

In addition, the perceived pain was reduced by 58% following cold exposure. This finding confirmed the analgesic effect of cryotherapy reported in recent studies (Dupuy et al., 2018; Lombardi, Ziemann, & Banfi, 2017). It is recognized that the exposure to cold stimulates the production of beta-endorphin, a neurotransmitter exerting analgesic effects, responsible for a sense of well-being (Leppäluoto et al., 2008), which may explain the improved morning form state and reduced muscle soreness. Also, noradrenalin is produced and also has analgesic properties (Leppäluoto et al., 2008). Moreover, skin temperatures reached 12°C at the end of exposure in some body areas. It was shown that a reduction of skin temperature below 13.6°C stimulates the analgesic effect of cryotherapy by blunting nerve conduction and acetylcholine formation (Bugaj, 1975).

The heart rate (HR) and heart rate variability (HRV) were considered physiological biomarkers related to sleep stages (Lan, Tsuzuki, Liu, & Lian, 2017). From a global view of the entire sleep night and the first 4-hour analysis, HRV was unaffected by cold exposure. By contrast, HRV analysis during the first detected SWS episode was dominated by parasympathetic activity in the WBC group. This finding was determined from a higher HF power (variations at normal respiratory frequencies, 9–24 times/min, 0.15–0.4 Hz), which is modulated by parasympathetic nervous systems inputs, and a decrease in the LF/HF ratio that indicates decreased sympathetic activity (Stein & Pu, 2012). In this sense, our results showed greater parasympathetic and lower sympathetic activity during the SWS episode following cold exposure. It is known that cold exposure prompted parasympathetic activity reactivation after physical exercise by increasing central blood volume and blood pressure (Mourot et al., 2008), which stimulates arterial and cardiopulmonary baroreceptors (Zalewski et al., 2014) that reduce sympathetic nerve activity and increase parasympathetic activity (Zalewski et al., 2014). These results were consistent with previous studies investigating the effect of cold exposure on the autonomic nervous system (Haddad et al., 2012; Schaal et al., 2015). Al Haddad et al (Haddad et al., 2012) observed that daily cold water immersion during a week of normal training in highly trained swimmers induced greater parasympathetic activity in the morning associated with better sleep quality. Similarly, Schaal et al. (Schaal et al., 2015) found that repeated WBC exposure reduced sympathetic activity following late night training, and these authors suggested that improved objective sleep quality may be related to decreased sympathetic activity and lowered arousal that may facilitate sleep onset. It could also be speculated that cryostimulation might have the power to readjust hormonal circadian rhythm and biological clock after a disturbance induced by an evening high-intensity exercise. Finally, we proposed that the improved subjective and objective sleep quality following cold exposure in athletes undergoing evening training may occur both from reduced perceived pain and greater parasympathetic activity that promotes a swift recovery. However, the physiological mechanisms underlying these improvements remain to be elucidated.

Conclusion

In conclusion, a 3-min single session of whole body cryotherapy in the evening improved the subjective and objective sleep quality in physically active men, but the physiological mechanisms responsible for this improvement are unclear. Further investigations are warranted to examine the relationship between heart rate variability changes during sleep and cold exposure with an accurate classification of sleep stages.

Disclosure statement

Romain Bouzigon, has been employed by Cryantal Development and is nowadays acting as a part-time consultant for Société Aurore Concept, 77186 Noisiel, France.

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