Journal of Thermal Biology 79 (2019) 144–148

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Effects of evening partial body cryostimulation on the skin and core temperatures

Masako Hoshikawa*, Michiko Dohi, Mariko Nakamura

Japan Institute of Sports Sciences, 3-15-1 Nishigaoka, Kita-ku, 115-0056 Tokyo, Japan

ARTICLE INFO

Keywords:
Partial body cryostimulation
Core temperature
Skin temperature

ABSTRACT

Cryostimulation is widely used to treat inflammation, rheumatism, acute soft tissue injuries, and neurodegeneration. It helps prevent injury and promotes recovery. This study aimed to examine the duration of the effects of evening partial body cryostimulation (PBC) on core and skin temperatures. Seven male athletes participated in this study. On the day of PBC, at 18:00, each athlete was exposed to PBC (approx. −180 °C) in a specially designed cabin for 3 min. On the control day, at 18:00, the participants sat still on a sofa for 10 min. On both days, bedtime was at around 23:00. Wrist and abdominal skin temperatures, except during PBC, were recorded with Thermochron thermistors after 17:30. Core temperatures were monitored with an ingestible and telemetric core body temperature sensor and a data recorder. The circadian rhythm of the core temperature was observed on both days. The core temperature at 22:30 was found to be lower on the PBC day. Wrist and abdominal skin temperatures recovered after PBC; however, the residual effects on both were different. The abdominal skin temperature at 22:30 was lower on the PBC day. Subjective sleep quality and next morning sleepiness did not differ between the conditions. These results suggested that the effects of a 3-min evening PBC session on the core and skin temperatures lasted for several hours. However, these differences did not affect the subjective sleep quality.

1. Introduction

Recently, cryostimulation has been widely used for various purposes, including treatment of inflammation (Pournot et al., 2011), rheumatism (Yamauchi, 1989), and fibromyalgia (Bettoni et al., 2013). Cryostimulation is used to relieve depression and anxiety syndromes (Rymaszewska et al., 2008). Cryostimulation is also becoming popular amongst athletes and clinicians to prevent injury and promote recovery (Paddon-Jones and Quigley, 1997; Banfi et al., 2009; Hausswirth et al., 2011; Schaal et al., 2015).

Techniques for cryostimulation involve exposing the whole or part of the body to cold air. In sports medicine, whole-body cryostimulation (WBC) consists of acute exposure to cold air (usually between −60 to −135 °C) in a specially designed chamber. Athletes enter the vestibule chamber (at −60 °C) for approximately 30 s for body adaptation, and then a cryochamber (between −110 and −135 °C), where they stay for up to 3 min. In contrast, during partial body cryostimulation (PBC), an athlete stands inside a specially designed cabin and his entire body, except for the neck and head, is exposed to cold air (usually between −160 and −195 °C). For PBC, the temperature inside the cabin was regulated through injections of liquid nitrogen, which boils at −196 °C at normal atmospheric pressure. It is noteworthy that the temperatures described above were as reported by manufacturers. The heat of the participant's body affects the temperature inside a chamber or a cabin. Savic et al. (2013) reported that the actual temperatures measured next to the skin were higher than those reported by the manufacturers. Nevertheless, WBC and PBC differ regarding the body areas exposed to the cold air, and the temperatures used for cryostimulation.

Many studies have evaluated the changes in skin temperature following WBC and PBC and focused on the extent to which cryostimulation lowered the temperature (Costello et al., 2012; Fond et al., 2014; Selfe et al., 2014; Hausswirth et al., 2013). However, there is a scarcity of research on the body's thermal responses for several hours after cryostimulation (Zalewski et al., 2014). Therefore, the duration of the effects of a cryostimulation session is still unclear.

Schaal et al. (2015) reported that WBC mitigated the signs of functional overreaching, such as reduced sleep. Additionally, Bouzigon et al. (2014) reported that WBC improved subjective sleep quality in athletes after matches. In both these studies, WBCs were conducted in the evenings, and their findings may imply that effects of the evening

Abbreviations: PBC, Partial Body Cryostimulation; WBC, Whole body cryostimulation; BMI, Body mass index; CON, control; CRY, cryostimulation

* Corresponding author.
E-mail address: masako.hoshikawa@jpnsport.go.jp (M. Hoshikawa).

https://doi.org/10.1016/j.jtherbio.2018.12.016
Received 10 August 2018; Received in revised form 12 December 2018; Accepted 12 December 2018
Available online 15 December 2018
0306-4565/

cryostimulation last until bedtime and may improve nocturnal sleep. However, no available data show that the effects of evening PBC last for several hours. In this study, we prescribed a 3-min PBC session at 18:00 to the participants. The purpose was to examine the duration of the effects of our intervention on the core and skin temperatures.

2. Material and methods

2.1. Subjects

Seven active males (age = 22.7 ± 1.7 years; height = 170.3 ± 2.8 cm; weight = 65.5 ± 4.6 kg; BMI = 22.6 ± 1.8 kg/m^2) participated in the study. The participants were national level triathletes (n = 2), college level athletes (n = 3), retired athlete (n = 1), a strength training professional (n = 1). It was the first time any of the participants were being prescribed PBC. The participants maintained regular sleeping habits and were not medicated with psychoactive agents or other medications. They were studied during the off-season and were prohibited from training after 12:00 on the PBC days. Smoking and alcohol consumption were prohibited. Written informed consent was obtained from all the participants after explaining to them the experimental procedure and possible risks. This study was approved by the Japan Institute of Sports Sciences Ethics Committee.

2.2. Study design

The participants were divided into 2 groups. In a crossover design, the participants were subjected to two measurements on the habitual day (CON) and the PBC day (CRY). Both the measurements were conducted within a month at the Japan Institute of Sports Sciences, Tokyo, Japan. The institute was air-conditioned, and the room temperature was 22.0 ± 0.85 °C.

Fig. 1 shows the schedule for the measurements. On each day, the participants came to the laboratory at 15:00. For the CRY condition, they moved to the room for the PBC at 17:45. Next, they sat still and waited for PBC until 18:00, and at 18:00 they were exposed to the PBC. For the CON condition, after sitting still for more than 10 min, the participants' core and skin temperatures were evaluated at 18:00. For both the conditions, at the restaurant in our institute, the participants had their dinner before 20:00. Next, they stayed in the institute dormitory room and were requested to go to bed around 23:00, and sleep for more than 7 h. Immediately on waking up, they filled the questionnaire sheet that asked about their sleep and feelings. For both conditions, the core and skin temperatures were continuously recorded from 17:30 on the day of CON or CRY until they woke up the next morning (except during PBC).

2.3. Partial body cryostimulation

Each participant was exposed to PBC for 3 min (Cryoshower CS-2000, Saraya Co., Ltd., Japan). For PBC, the temperature inside the cabin was regulated through injections of liquid nitrogen, which boils at −196 °C at normal atmospheric pressure. The temperature at the outlet for the nitrogen was regulated at −180 °C. It should be noted that, due to the convection from the participant's body to the air in the cabin, the actual temperature next to the skin may have been higher. Savic et al. (2013) reported that the actual temperature next to the skin often reaches −35 °C during 3-min PBC.

The participant entered the cabin in swimwear, equipped with gloves, socks, and shoes to prevent frostbite of the extremities. By adjusting the height of the platform in the cabin, his head and neck were outside the cabin and were not exposed to the nitrogen gas. During the PBC, he was allowed to move his extremities and turn around slowly inside the cabin.

2.4. Core body temperature measurements

The core body temperature was determined using an ingestible telemetric temperature capsule system (CorTemp, HQInc, USA). The system comprised of two components: i) a portable monitor for registering, storing, and exporting digital records of temperature, and ii) an ingestible capsule-type sensor for measuring temperature.

Around 15:30, each participant swallowed the capsule with a small amount of water. The participant's core temperature was recorded once every minute, from 17:30 until the participant woke up the next morning (except during the PBC).

2.5. Skin temperature measurements

The wrist and abdominal skin temperatures were recorded using the iButton wireless temperature system (type DS1921H; Maxmim/Dallas Semiconductor Corp., USA). It is a small (diameter = 17 mm; height = 7 mm; weight = 3.3 g) system for measuring and recording temperature. Next, the time and temperature data were transferred to a computer for data analysis. To record the temperatures, the bottom of each iButton was attached to the skin of the non-dominant wrist and abdomen using an adhesive tape at 15:00. Wireless determination skin temperature using iButton has already been validated (Marken Lichtenbelt et al., 2006; Hasselberg et al., 2013). The recording interval was set at 1 min. Data collected between 17:30 and 18:00 and after 18:30 were analyzed.

The iButton wireless temperature system used in this study does not start recording skin temperatures instantly. Therefore, we adopted supplemental measurements of skin temperatures using a non-contact digital infrared thermometer (DT-8806H, MK Scientific, Inc., Kanagawa, Japan), immediately after PBC. The supplemental measurements of skin temperatures were performed at the suprasternal region, the right side of the navel, and the upper part of the thigh.

2.6. Subjective sleep quality and sleepiness

The participants were also asked to assess their sleep quality and sleepiness immediately after waking up. Subjective sleep quality was assessed using the 5-point Likert scale question (1: Could not sleep at all – 5: Slept very well). Sleepiness was assessed utilizing the Karolinska Sleepiness Scale (Akerstdt and Gillberg, 1990).

2.7. Statistics

Data are expressed as means ± standard deviation (SD). The Shapiro-Wilk test was used to assess normal distribution of data. In this study, skin and core temperatures at 17:30, 19:00, 22:30, and 6:00 for

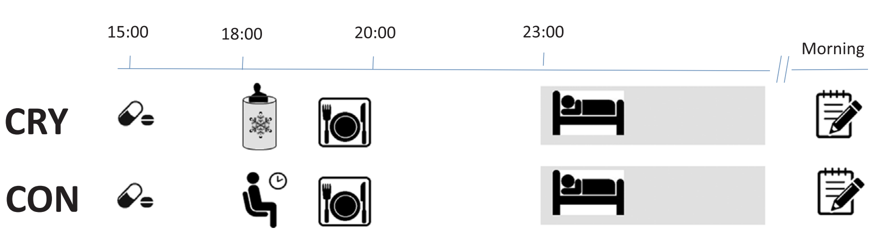

Fig. 1. Temperature measurement schedule.

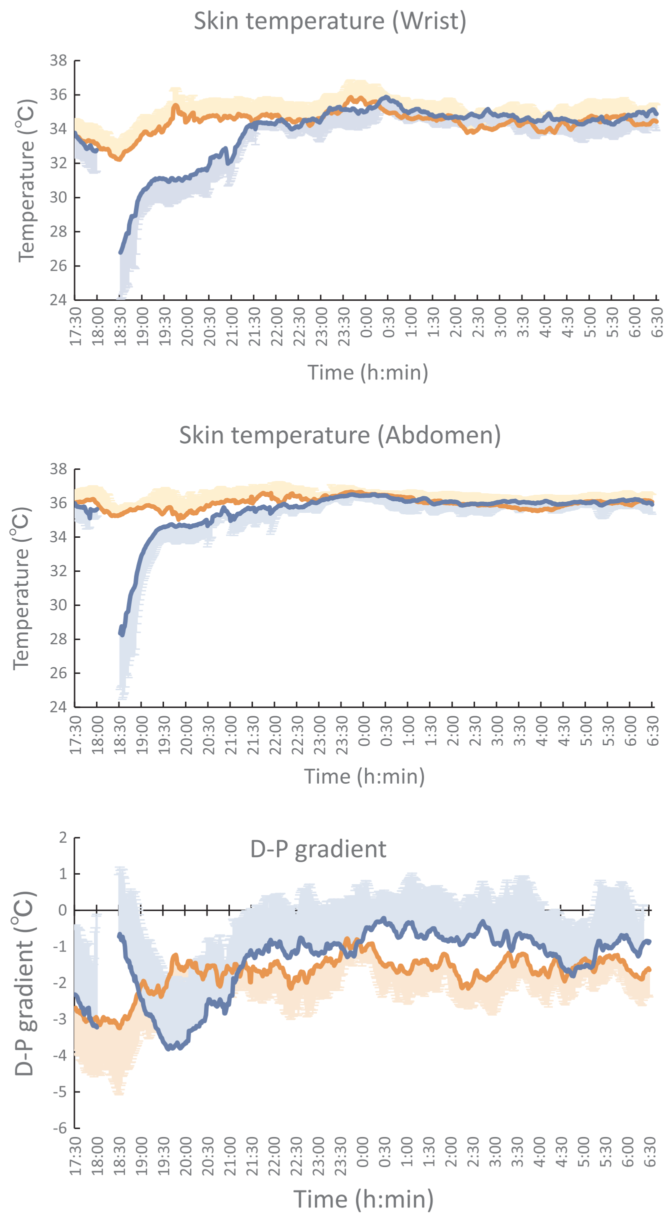

Fig. 2. Mean and standard deviation (SD) of skin temperatures from the wrist and abdomen, and the distal (wrist) – proximal (abdomen) gradients of skin temperature. Bold orange line indicates control condition; bold blue line indicates cryostimulation condition; thin vertical lines indicate the SD for the mean data in both the conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

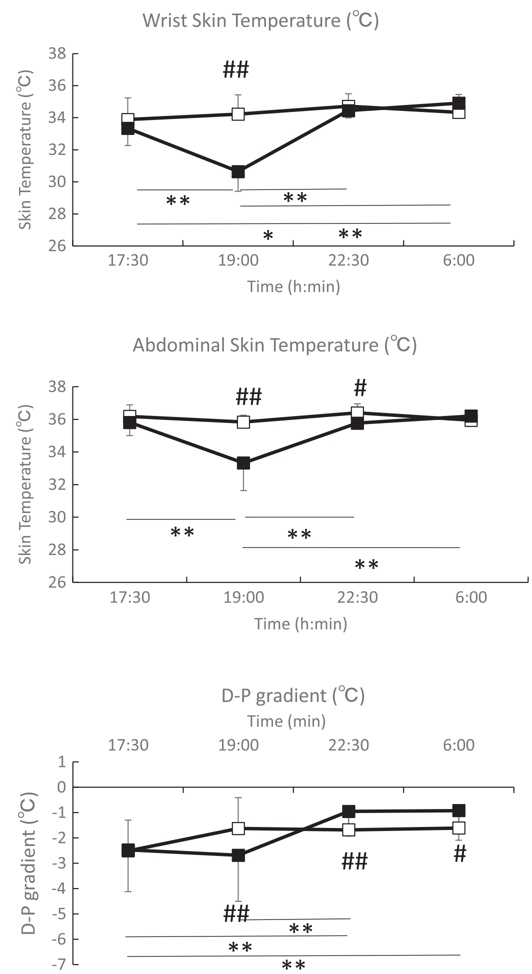

Fig. 3. Mean and standard deviation (SD) of skin temperatures from the wrist and abdomen, and the distal (wrist) – proximal (abdomen) gradients of skin temperature at the selected 4 time points. Open squares (□) indicate control condition; Closed squares (■) indicate cryostimulation condition. # $p < 0.05$ between the conditions; ## $p < 0.01$ between the conditions; * $p < 0.05$ between the time points within the condition; ** $p < 0.01$ between the time points within the condition.

the conditions were compared. For these temperatures, statistical multiple comparison was performed by Tukey method. For Subjective sleep quality and Karolinska sleepiness scale, paired *t*-test was used. These analyses were done with the Ekuseru-Toukei 2012 statistical package (Social Survey Research Information Co., Ltd., Tokyo, Japan). Statistical significance was set at $p < 0.05$.

3. Results

The supplemental measurements of skin temperatures, obtained using a non-contact digital infrared thermometer, immediately after PBC demonstrated that the temperatures were 25.8 ± 2.18 °C at the suprasternal region, 16.9 ± 2.15 °C at the right side of the navel, and 6.0 ± 5.47 °C at the upper part of the thigh.

Results of skin temperatures obtained using the iButton wireless temperature system showed that both the wrist and abdominal skin temperatures were lowered by PBC (Figs. 2 and 3). For both the wrist and abdomen, the cryostimulation lowered the skin temperature, and its effects were still noted at 19:00. For the CRY condition, the skin temperatures at 19:00 were significantly lower than at the other time points. The skin temperatures recovered after then; however, the residual effects on both were different. The abdominal skin temperature at 22:30 was lower for CRY condition (Fig. 3). Figs. 2 and 4 also show the mean and SD for the distal (wrist) – proximal (abdomen) skin temperature gradients. PBC lessened the gradient; however, the transient increments in the gradients were observed later. After the transient increments, the gradients lessened again (Fig. 2). At the selected 4 time points, statistical differences between the conditions appeared at and after 19:00. For CRY condition, D-P gradients at 17:30 and 19:00 were greater than at 22:30 and 6:00 (Fig. 3).

The mean and SD of core temperatures for both conditions are shown in Figs. 4 and 5. For both conditions, circadian rhythm of the core temperature was observed. The core temperature at 6:00 was lower than at the other time points. Statistical difference between the conditions was observed at 22:30 (Fig. 5).

Subjective sleep quality was 3.57 ± 0.90 and 3.71 ± 0.88 for the CRY and CON condition, respectively. The Karolinska sleepiness scale score was 2.71 ± 1.57 and 4.14 ± 1.72 for the CRY and CON

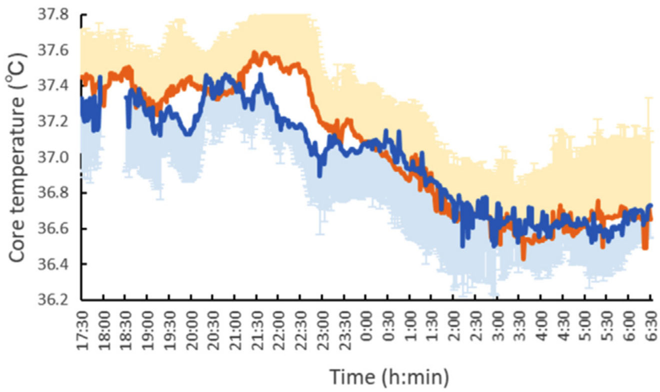

Fig. 4. Mean and standard deviation (SD) of core temperatures for both conditions. Bold orange line indicates control condition; bold blue line indicates cryostimulation condition; thin vertical lines indicate the SD for the mean data in both the conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

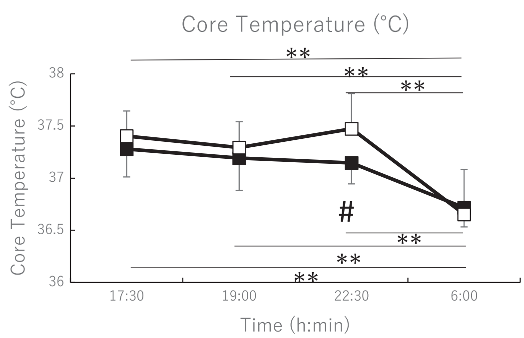

Fig. 5. Mean and standard deviation (SD) of core temperatures at the selected 4 time points. Open squares (□) indicate control condition; Closed squares (■) indicate cryostimulation condition. # $p < 0.05$ between the conditions; * $p < 0.05$ between the time points within the condition; ** $p < 0.01$ between the time points within the condition.

condition, respectively. For both parameters, the differences between the conditions were insignificant.

4. Discussion

The two major findings from this study are that evening PBC 1) affected the core and skin temperatures for several hours, and 2) did not affect the participants' subjective sleep quality.

Our study results for the skin temperatures after PBC are comparable to those of previous studies (Fonda, 2014, Hausswirth et al., 2013; Savic, 2013; Westerlund et al., 2003). Since cold air has a higher density than warm air, the lower part of the PBC cabin might be colder than the upper part (Savic et al., 2013) and may affect skin temperatures following PBC influencing the skin temperature restoring process. Westerlund et al. (2003) compared the skin temperature from 8 different surface areas before, during, and after WBC (Chamber type) demonstrating that the lowest temperature and temperature changes, 0–30 min after cryostimulation, varied with the surface areas. We hypothesize that the athletes' thermal responses to cold air and the air temperature inside the PBC cabin contributed to our results.

Our results suggest that evening PBC affected core temperatures for several hours (Figs. 4 and 5). One of the reasons might be the venous return of cool blood from the periphery to the core. Other possible reasons are heat redistribution by distal vasodilation (Rubinstein and Sessler, 1990), and thermal conduction between the tissue from the periphery to the internal territories. Although the large distal-proximal gradients were observed immediately after the cryostimulation, these two restoring processes may have accelerated the narrowing of the gradients. Additionally, it is well-known that core temperature exhibits a circadian rhythm, peaking in the evening and lowering near bedtime (Aschoff, 1983). In this study, PBC lowered the peak core temperature in the evening probably due to the venous return of cold blood to the core and heat redistribution. Circadian lowering of the core temperature was observed irrespective of the cryostimulation (Figs. 4 and 5). Time at the lowest temperatures, circadian phase-shift indicator, did not change after PBC (Fig. 4). Importantly, the lower core temperature was maintained for several hours in the CRY condition.

As stated in the introduction, there are researches reported that evening cryostimulation improved nocturnal sleep. It is well-known that decline in core temperature (Murphy and Campbell, 1997) and distal-proximal skin temperature gradient promotes rapid onset of sleep (Kurauch et al., 1999). Although the evening PBC affected the core temperature (Fig. 5) and the distal-proximal skin temperature gradient (Fig. 3), evening PBC did not improve subjective sleep quality and morning sleepiness. There are several reasons for the differences in the results of previous studies and ours. As described in the introduction, the previous studies (Bouzigon et al., 2014; Schaal et al., 2015) applied WBC to their athletes. WBC, which includes exposing the head and neck to cold stimulus, would elicit greater stimulation than PBC. Louis et al. (2015) reported that WBC stimulated the autonomic nervous system with a predominance of parasympathetic tone activity greater than what PBC effected. Moreover, in the previous studies, WBC was applied to the athletes in situations where sleep quality is known to be impaired. In contrast to our participants, the athletes in these studies were functionally overreaching (Schaal et al., 2015) or competing in matches in the afternoon and/or evening (Bouzigon et al., 2014). Both core and skin temperatures and the reactivity of the autonomic nervous systems in the athletes might therefore show different patterns compared to those in our study. These may have caused the differences in the results of previous studies and ours.

There are some limitations to this study. Firstly, the iButton wireless temperature system does not start recording skin temperatures instantly. We have to adopt supplemental measurements of skin temperatures, using a non-contact digital infrared thermometer, immediately after PBC. We could not measure skin temperature continuously using one temperature measurement system. This was a technical limitation of this study. Secondly, our subjects were young male athletes and had a relatively lower BMI (22.6 kg/m^2 on average). Our participants comprised two triathletes, a lacrosse player, a football player, a baseball player, a retired kayaker, and a strength training professional. Their BMI ranged from 20.6 kg/m^2 to 26.0 kg/m^2, but 6 of 7 athletes showed a BMI < 25.0 kg/m^2. Cholewka et al. (2012) reported that skin temperature decreased by 7.9–8.1 °C in a thin participant (BMI < 25 kg/m^2) and increased by 4.8–5.5 °C in an obese participant (BMI > 30 kg/m^2). Hammond et al. reported that body fat percentage in males correlated with the changes in skin temperature following WBC. Not only muscle mass and body composition, but also autonomic nervous system function might have influenced our results. Our participants were from various sporting backgrounds. Since the autonomic nervous system functions in athletes from aerobic or anaerobic sports may be adapted differently (Smith et al., 1988), our results may have partially reflected individual differences in the functions. Furthermore, Hammond et al. (2014) reported that the cooling efficiency of WBC is potentially greater in females than in males. Their study suggested that a higher surface area-to-mass ratio, a higher percentage of body fat, and extensiveness of peripheral vasoconstriction are critical factors. Thus, our results may be partially dependent on the physical and physiological characteristics of the participants. Thirdly, there is a possibility that the food and drink intake could have influenced our results. We did not manage the amount of calories and nutrients in the participants' meals. The restaurant in our institute changes its menu daily, and our participants chose their meals from this menu. However, only one or two participants were studied daily, which might have helped to lessen the effects of nutrients.

In this study, the participants slept in a relatively cool environment (22.0 °C). It is well known that sleep disturbances in hot environments are related to the impaired decline in the core temperature. There is still the possibility that lowering the core temperature using PBC might help improve sleep in hot environments. Further studies are needed to clarify this.

5. Conclusion

This study is the first to demonstrate that a 3-min session of PBC in the evening affects core and skin temperatures for several hours. Following evening PBC, abdominal and wrist skin temperatures restored differently. These induced transient increments followed by a decline in the distal-proximal skin temperature gradient and resulted in core temperature decline. Although these may have a possibility to improve nocturnal sleep, our intervention did not change the participants' subjective sleep quality and morning sleepiness. We tested them on a non-training day in a relatively cool environment. There is still a possibility that PBC affects nocturnal sleep in other situations. Further studies are necessary to explore the possibility.

Acknowledgment

We thank Ms. Emi Narumi and the staffs working for High Performance Gym in our institute, for their technical assistance during the measurements. This research was carried out as a part of the Research Project of Japan Institute of Sports Sciences.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that they have no conflicts of interest.

Declarations of interest

None.

References

Akerstdt, T., Gillberg, M., 1990. Subjective and objective sleepiness in the active individual. Int. J. Neurosci. 52, 29–37.
Aschoff, J., 1983. Circadian control of body temperature. J. Therm. Biol. 8, 143–147.
Banfi, C., Melegati, G., Barassi, A., Dogliotti, G., Melzi, d'Eril, G., Dugue, B., Corsi, M., 2009. Effects of whole-body cryotherapy on serum mediators of inflammation and serum muscle enzyme in athletes. J. Therm. Biol. 34 (55–59), 2009.
Bettoni, L., Bonomi, F.G., Zani, V., Manisco, L., Indelicato, A., Lanteri, P., Benfi, G., Lombardi, G., 2013. Effects of 15 consecutive cryotherapy sessions on the clinical output of fibromyalgic patients. Clin. Rheumatol. 32, 1337–1345.
Bouzigon, R., Raivier, G., Dugue, B., Grappe, F., 2014. The use of whole-body cryostimulation to improve the quality of sleep in athletes during high level standard competitions. Br. J. Sports Med. 48 (7), 572.
Cholewka, A., Stanek, A., Sieron, A., Drzazga, Z., 2012. Thermography study of skin response due to whole-body cryotherapy. Skin. Res. Technol. 18 (2), 180–187.
Costello, J.T., Culligan, K., Selfe, J., Donnelly, A.E., 2012. Muscle, skin, and core temperature after −110°C cold air and 8°C water treatment. PLoS One 7 (11), e48190 (2012).
Fond, B., De Nardi, M., Sarabon, N., 2014. Effects of whole-body cryotherapy duration on thermal and cardio-vascular response. J. Therm. Biol. 42, 52–55.
Hammond, L.E., Cuttell, S., Nunley, P., Meyler, J., 2014. Anthropometric characteristics and sex influence magnitude of skin cooling following exposure to whole body cryotherapy. BioMed. Res. Int. https://doi.org/10.1155/2014/628724. (Article ID: 628724).
Hasselberg, M.J., McMahon, J., Parker, K., 2013. The validity, reliability, and utility of the iButton for measurement of body temperature circadian rhythms in sleep/wake research. Sleep. Med. 14, 5–11.
Hausswirth, C., Louis, J., Bieuzen, F., Pounot, H., Fournier, J., Filliard, J.R., Brisswalter, L., 2011. Effects of whole-body cryotherapy vs Far-infrared cs passive modalities on recovery from exercise-induced muyscle damege in highly-trained runners. PLoS One 6 (12), e27749.
Hausswirth, C., Schaal, K., le meur, Y., Bieuzen, F., Fillard, J.R., Volondat, M., Louis, J., 2013. Parasympathetic activity and blood catecholamine response following a single partial-body cryostimulation and whole-body cryostimulation. PLoS One 8 (8), e72658.
Kurauch, K., Cajochen, C., Werth, E., Wirz-Justice, A., 1999. Warm feet promote the rapid onset of sleep. Nature 401, 36–37.
Louis, J., Schaal, K., Biuezen, F., Le Meur, Y., Filliard, J.R., Volondat, M., Brisswalter, J., Hausswirth, C., 2015. Head exposure to cold during whole-body cryostimulation: influence on thermal response and autonomic modulation. PLoS One 10 (4), e0124776.
Marken Lichtenbelt, W.Dv, Daanen, H.A.M., Wouters, L., Fronczek, R., Raymann, R.J.E.M., Severens, N.M.W., Van Somern, E.J.W., 2006. Evaluation of wireless determination of skin temperature using iButtons. Physiol. Behav. 88, 489–497.
Murphy, P.J., Campbell, S.S., 1997. Sleep onset: Nighttime drop in body temperature: a physiological trigger for sleep onset? Sleep 20 (7), 505–511.
Paddon-Jones, D.J., Quigley, B.M., 1997. Effect of cryotherapy on muscle soreness and strength following eccentric exercise. Int. J. Sports Med. 18, 588–593.
Pournot, H., et al., 2011. Time-course of changes in inflammatory response after whole-body cryotherapy multi exposure following severe exercise. PLoS One 6 (7), e22748.
Rubinstein, E.H., Sessler, D.I., 1990. Skin-surface temperature gradients correlate with fingertip blood flow in humans. Anesthesiology 73, 541–545.
Rymaszewska, J., Ramsey, D., Chladzinska-Kiejna, J.R., 2008. Whole-body cryotherapy as adjunct treatment of depressive and anxiety disorders. Arch. Immunol. Ther. Exp. 56, 63–68.
Savic, M., Fonda, B., Sarabon, N., 2013. Actual temperature during and thermal response after whole-body cryotherapy in cryo-cabin. J. Therm. Biol. 38, 186–191.
Schaal, K., Meur, Y., Louis, J., Filliard, J.R., Hellard, P., Casazza, G., Hausswirth, C., 2015. Whole-body cryostimulation limits overreaching in elite synchronized swimmers. Med. Sci. Sports Exerc. 47 (7), 1416–1425.
Selfe, J., Alexander, J., Costello, J.T., May, K., Garratt, N., Atkins, S., Dillon, S., Hurst, H., Davion, M., Przybyla, D., Coley, A., Bitcon, M., Litter, G., Richards, J., 2014. The effect of three different (−135°C) whole body cryotherapy exposure durations on elite rugby league players. PLoS One 9 (1), e86420.
Smith, M.L., Graitzer, H.M., Hudson, D.L., Raven, P.B., 1988. Baroreflex function in endurance- and static exercise-trained men. J. Appl. Physiol. 64 (2), 585–591.
Westerlund, T., Oksa, J., Smolander, J., Mikkelsson, M., 2003. Thermal responses during and after whole-body cryotherapy (−110°C). J. Therm. Biol. 28, 601–608.
Yamauchi, T., 1989. Whole-body cryotherapy is a method of extreme cold −175°C treatment initially used for rheumatoid arthritis. Z. Phys. Med. Brain Med. Klin. 13, 311.
Zalewski, P., Bitner, A., Slomko, J., Szrajda, J., KLawe, J.J., Tafil-Klawe, M., Newton, J., 2014. Whole-body cryostimulation increases parasympathetic outflow and decreases core body temperature. J. Therm. Biol. 45, 75–80.