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Effects of cryo-facial mask on running performance in amateur middle-distance runners

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ABSTRACT

The excess heat accumulated during exercise can lead to stress-induced fatigue, possibly impairing athletic performance. Various precooling techniques have been applied to enhance thermal comfort, reduce perception of effort, and improve endurance. In this randomized crossover study, twelve male amateur middle-distance runners (age: 33.69 ± 5.9 years; body mass: 71.9 ± 4.4 kg; height: 178.4 ± 5.6 cm; $\dot{V}O_2$ peak: 63.3 ± 5.6 mL $min^{-1} \cdot kg^{-1}$) wore a facial cooling mask before a time-to-exhaustion (TTE) test on a treadmill, under cryostimulation or control conditions. The running performance comprised also two constant load trials, one conducted before and another after wearing the mask, both performed at the velocity of the first ventilatory threshold. Under cryostimulation condition, the TTE was 13 % higher than the control condition ($p = 0.0049$; $d = -0.19$) with a significant main effect of time for both ratings of perceived exertion ($F_{1, 22} = 50.10$; $p < 0.0001$; $\eta^2p = 0.69$) and heart rate ($F_{1, 22} = 31.53$; $p < 0.0001$; $\eta^2p = 0.59$). A significant interaction "condition × time" was found for facial skin temperature ($F_{2, 44} = 36.93$; $p < 0.0001$; $\eta^2p = 0.63$) and for heart rate during the constant load trial after wearing the mask ($F_{1, 22} = 5.90$; $p = 0.0238$; $\eta^2p = 0.21$). The localized cryostimulation provided by the mask lowered the skin temperature on the face, potentially mitigating the negative effects of heat stress during running. Incorporating the cryo-facial mask as part of a pre-exercise routine for runners may offer a practical and convenient method to optimize performance and enhance overall training outcomes.

1. Introduction

The human body can achieve remarkable levels of physical performance; however the majority of energy produced during exercise is converted to heat (~70–80 %), rather than mechanical work [1]. This excess heat can accumulate and lead to heat-stress-induced fatigue, which can significantly impair athletic performance [2]. Heat-stress-induced fatigue leads to a reduced central nervous system (CNS) drive to the skeletal muscle resulting in central fatigue [1,2]. Concurrently, it adversely impacts cardiovascular function, which subsequently reduces the oxygen supply delivered to the working muscles, resulting in peripheral fatigue [1,2]. Athletes employ various strategies, either before or during exercise, to mitigate these negative effects. Endurance running demands sustained aerobic effort, relying on optimal physiological and thermoregulatory mechanisms for peak performance. As athletes push their limits, researchers and coaches seek innovative strategies to improve performance and minimize the effects of environmental stressors [3,4]. A burgeoning area of interest is the use of precooling techniques, which involve adjusting the body's temperature prior to exercise initiation. In this regard, precooling modalities primarily result in reduced resting skin temperature and subsequently core temperature, thereby increasing the so-called 'heat storage capacity' and delaying the onset of thermally-induced fatigue [5,6]. Precooling has been shown to have a positive impact on the mechanisms responsible for heat-stress-induced fatigue [7]. The effects of precooling include increased perfusion of working muscles through peripheral vasoconstriction caused by reduced skin temperature. Moreover, precooling alters thermal perception and diminishes inhibitory signals from the central nervous system, which are activated by the body's defenses against overheating [2,6].

Precooling techniques involve exposure to very cold air, iced water, or the application of cold substances such as gel packs, wet towels, cold vests, water spray, or ice. Although whole-body precooling offers its benefits, it poses logistical challenges when it comes to incorporating them close to the event to maintain the desired physiological alterations, such as reduced skin temperature [8].

Consequently, athletes, coaches, and practitioners are in search of practical and minimally demanding protocols for localized precooling to

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achieve effective results.

Previous investigations have shown that localized precooling may be a promising approach to enhance sports performance [5,9,10]. It is widely recognized that the face and neck regions of the head exhibit heightened sensitivity to thermal stimuli compared to the rest of the body. As a result, applying a cold stimulus to these areas during heat stress situations can lead to a significant reduction in perceived heat discomfort. This reduction in thermal discomfort has been shown to improve athletic performance, particularly during endurance exercises and repeated sprint training conducted in hot environments, without compromising the body's thermoregulatory response [11]. Considering these factors, localized face precooling emerges as a promising solution to enhance performance.

While precooling strategies have shown effectiveness in mitigating the effects of heat stress, their practical implementation is often hampered by logistical challenges. These challenges include the need for significant amounts of water and/or ice, time-consuming procedures, and the difficulty of administering them simultaneously to a large number of individuals, as may be required in team sports settings [5]. Consequently, the development of novel, practical, and efficient approaches could offer an optimal solution to enhance performance.

In this regard, a novel model of local cryostimulation device called X°CRYO (CTN, Helsinki, Finland) has recently emerged. This portable electric system utilizes very cold dry air (−28 °C) generated by forced convection, creating a wind chill effect resulting in a uniform reduction of skin temperature across the entire facial region. Given that a single session can last up to 3 min, it holds significant promise for effective integration into precooling protocols for use in sports venues. To date, no research has been conducted to investigate the potential impact of face cooling on time to exhaustion in trained endurance athletes under thermoneutral conditions. Therefore, the present study aims to assess whether the application of a cryo-facial mask as a precooling strategy can influence performance and perceptual responses during exhaustive and submaximal runs in thermoneutral conditions.

2. Materials and methods

2.1. Participants

The sample size was based on previous studies completed in our laboratory, in order to lead the subjects up to exhaustion within the planned experimental duration. In addition, this size sample was consistent with those reported in the available literature on facial precooling [11]. In particular, means and standard deviations of key variables previously investigated – such as RPE, HR, and skin temperature – were considered. Therefore, twelve male endurance-trained runners were recruited (age: 33.69 ± 5.9 years; body mass: 71.9 ± 4.4 kg; height: 178.4 ± 5.6 cm; $\dot{V}O_2$peak: 63.3 ± 5.6 mL $min^{-1}\cdot kg^{-1}$) on a voluntary basis. The inclusion criteria for participants were as follows: having a minimum of 2 years of running experience, regular participation in competitions (Tier 2, "Trained/Developmental" according to McKay et al.'s classification [12]), and no known diseases or exercise limitations. All participants underwent a thorough examination by a qualified physician to ensure that there were no skin contraindications, such as rosacea or cold urticaria, that could affect the exposure of the face region to cold. Participants were instructed to maintain their regular diet, stay hydrated, avoid alcohol, caffeine, and strenuous exercise for at least 24 h before the testing sessions. Each athlete was informed about the procedures and associated risks and provided written informed consent to participate in the study. Although the subjects were not fully informed about the experimental conditions and were kept unaware of the research hypotheses, the complete blinding was not possible due to the changes in thermal sensation experienced during the study. The study design and procedures were approved by the institutional ethics committee (Approval no. 52/20, attachment 4) and adhered to the ethical principles for medical research involving human participants as outlined in the latest version of the World Medical Association Declaration of Helsinki.

2.2. Design

A randomized counterbalanced crossover study design was conducted over a period of four weeks, with one session per week at the same time of day. During the first session, a familiarization procedure was carried out (see "familiarization procedure" paragraph). Before the familiarization visit, participants were randomly assigned to start the experimental protocol with one of the two experimental sessions (MASK or control) based on balanced permutations generated by a web-based computer program (www.randomization.com). In the second session, participants underwent a maximal incremental running test to determine their $\dot{V}O_2$peak, velocity at $\dot{V}O_2$peak (v$\dot{V}O_2$peak), and velocity at the first ventilatory threshold (vVT_1). The third and fourth visits (Fig. 1) involved completing an 18-min constant load trial at vVT_1 (CLT-PRE) as a warm-up, followed by either the 3-min experimental treatment (MASK) or control in a counterbalanced order (see "Cryo-facial mask procedures" section). Immediately after the treatment, participants performed a 6-min constant load trial at vVT_1 (CLT-POST), followed immediately by a time to exhaustion test (TTE) at v$\dot{V}$O2peak (Fig. 1). All running tests were conducted on the same motorized treadmill (Run Excite 500, Technogym, Cesena, Italy). Each subject completed all sessions within a maximum of 30 days and within their usual training timeframe. The testing environment was maintained at a moderate level (temperature: 21.1 ± 0.8 °C; humidity: 50.6 ± 6.8 %). Participants arrived at the laboratory 30 min before the tests and acclimated to the room while resting on a bench, wearing their racing suit and running shoes. To ensure accurate analysis of their thermographic images, participants were required to be shaved. No participants dropped out, and no deviations from the experimental procedures were registered.

2.3. Familiarization procedure

During visit 1, anthropometric measurements of the participants were recorded. Subsequently, participants underwent a familiarization session on the same treadmill used for the tests. During this session, they ran at a speed of 10 km h^{-1} for 20 min while wearing the portable gas exchange system (PNOĒ, ENDO Medical, Palo Alto, CA), which was used for the maximal incremental test. In addition, during this run, participants were familiarized with the CR-10 Borg scale [13,14] to assess their perceived exertion. Furthermore, we used a high-frequency video camera (Sony, NEX-FS700R Super 35 Camcorder) to verify and confirm that the speed of the treadmill used in the study was consistent with the manufacturer's declared specifications.

2.4. Maximal incremental test

During visit 2, subjects completed a maximal incremental test on the same treadmill used during visit 1. The session began with a standardized warm-up consisting of 10 min of running at a constant speed of 10 km h^{-1} with the treadmill inclination set at 2 %. Following the warm-up, participants performed 5 min of mobility exercises. Subsequently, they had a 10-min rest period in a standing position while wearing the portable gas exchange system. The maximal incremental test started at a speed of 10 km h^{-1}, with the velocity increasing by 0.1 km h^{-1} every 12 s until voluntary exhaustion. Throughout the test, expired gases were recorded through the portable gas exchange system in breath-by-breath mode, calibrated following the manufacturer's recommendations. $\dot{V}O_2$peak was determined by calculating the mean highest 30-s oxygen consumption during the maximal incremental test. The velocities at the first ventilatory threshold (vVT_1) and second ventilatory threshold (vVT_2) were determined using the criteria of Binder and Colleagues

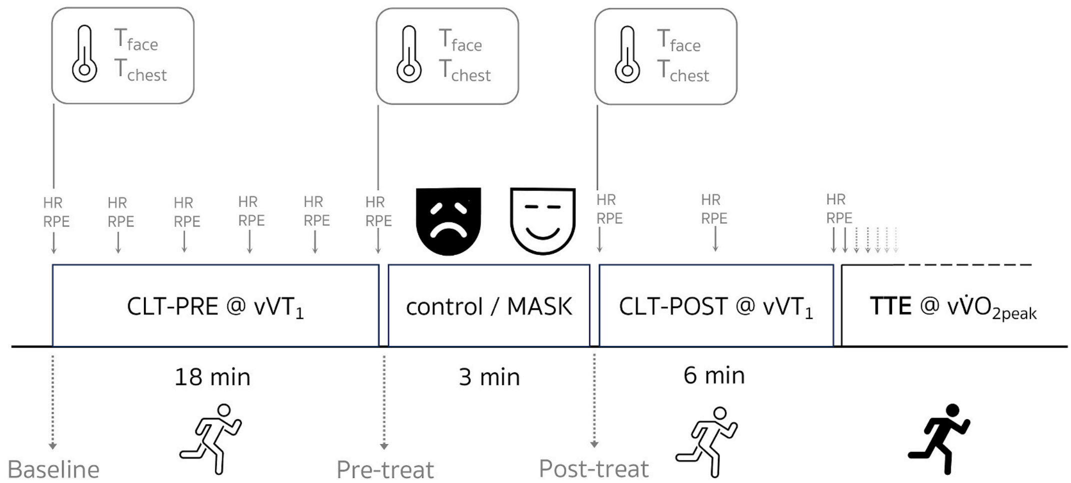

Fig. 1. Flow-chart of the design of the study and the experimental sessions.

[15]. Additionally, $v\dot{V}O_2$peak was determined as the minimal running velocity that elicited $\dot{V}O_2$peak [16].

2.5. Constant load trial and time to exhaustion

During CLT-PRE and CLT-POST subjects ran at the velocity corresponding to vVT_1 (10.63 ± 1.53 km h^{-1}) for 18 and 6 min, respectively. The CLT-PRE protocol served as a warm-up, while the CLT-POST protocol aimed to examine the potential effects of the treatment (control/MASK) on physiological and perceived responses during moderate-intensity exercise. Hence, the cooling strategy selected for this study could be classified as a pre-cooling method rather than a per-cooling one. Immediately after completing the CLT-POST, the treadmill speed was rapidly increased, and the TTE test commenced. Throughout the TTE test, participants were required to maintain a running velocity equivalent to $v\dot{V}O_2$peak until exhaustion. No feedback on running velocity or elapsed time, nor verbal encouragement, was provided during any of the tests. Participants were kept blind to their performance and physiological data until the completion of the entire protocol.

2.6. Physiological and perceptual measures

Heart rate (HR) and rating of perceived exertion (RPE) were measured every 3 min during both CLT-PRE and CLT-POST. During the TTE test, HR and RPE were measured every minute until the point of exhaustion. HR was recorded using a heart rate monitor equipped with a chest strap (H9, Polar, Kempele, Finland) and RPE was assessed using the CR10 Borg's scale. During the third and fourth visits, facial (T_{face}) and trunk (T_{chest}) skin temperatures were measured at three different time points: before CLT-PRE (Baseline), immediately after CLT-PRE (Pre-treat) and immediately after the intervention control/MASK (Post-treat) (Fig. 1). A thermal imaging camera (E54, FLIR Systems Inc., Danderyd, Sweden) was employed to measure skin temperature. The measurements followed the guidelines outlined in the Thermographic Imaging in Sports and Exercise Medicine (TISEM) checklist [17]. The assessments were conducted in a dark room with only the examinator and the subject present, ensuring that no other electronic devices were active except for the thermal camera used for the measurements [18]. This thermal camera had a resolution of 320 × 240 IR pixels, a temperature measurement range from −20 °C to 650 °C, a spectral range between 7.5 and 14 μm and an accuracy of ±2 °C. Thermal images were captured by the same expert evaluator, maintain a distance of 1.5 m from the subject. During the imaging process, participants were instructed to refrain from talking, rubbing their skin, or engaging in any activities that could potentially influence the values of skin temperature.

For the thermal analysis, the emissivity was set at 0.98 and two regions of interest (ROIs) were defined for the face and chest. An experienced operator with more than five years of thermal imaging analysis expertise defined the ROIs for each subject. The average skin temperature for each ROI was calculated using commercial software (Thermacam Researcher Pro 2.10, Flir Systems, Danderyd, Sweden).

2.7. Cryo-facial mask procedures

The facial cooling procedure (MASK) involved the use of a specialized mask integrated with an electricity-based localized cryostimulation device (X°CRYO, CTN, Helsinki, Finland). The mask had a shape resembling the human face and was designed to lower the skin temperature through a series of small holes that emitted very cold air. The X°CRYO device operated on the principle of forced convection. Participants were instructed to place the cryo-facial mask as close as possible to their face for a duration of 3 min, without removing it. All participants remained seated in a chair during the procedure. The entire operation was supervised by a qualified operator. In the MASK condition, the manufacturer-recommended settings were used, with an airflow speed of 12.7 ± 0.2 m s^{-1} and a cold air temperature of −28.0 ± 2.0 °C. In the control condition, participants wore the facial mask applicator for the same duration, but the cryostimulation device was inactive. All participants abided the MASK procedure well, and no adverse events or side effects were reported during or after the sessions.

2.8. Statistical analysis

Data are presented as mean ± standard deviation (SD). Normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was examined using Levene's test. To compare differences between conditions in TTE test and learning effect between MASK and control vs familiarization, a paired T-test was employed. A two-way repeated measure analysis of variance (ANOVA) was performed, with condition and time as factors, to evaluate the effect of MASK vs control on physiological outcomes across three-time points (baseline, pre-treat, post-treat). The Greenhouse-Geisser correction was used when sphericity was not met (Mauchly test). The significance level was set at 0.05 (two-tailed) for all analyses. Partial eta squared (η_p^2) was reported as the effect sizes for ANOVA, with interpretation of small (0.01), medium (0.06), and large (0.13) effect sizes [19]. Cohen's *d* was used to estimate the effect size, with interpretation of trivial (<0.20), small (0.21–0.60), moderate (0.61–1.20), large (1.21–2.00), or very large (>2.00) [20].

Data analysis was performed using the Statistical Package for the Social Sciences, version 25 (SPSS Inc.).

3. Results

A significant difference was found in TTE between the MASK and control conditions ($p = 0.0049$; $d = -0.19$; MASK = 251 ± 159 s, control = 222 ± 143 s; within-subject coefficient of variation = 9.1 %) (Fig. 2). TTE was not affected by learning effect ($p = 0.6780$). During the TTE, significant main effects of time were observed for both RPE ($F_{1, 22} = 50.10$; $p < 0.0001$; $\eta^2p = 0.69$) and HR ($F_{1, 22} = 31.53$; $p < 0.0001$; $\eta^2p = 0.59$). However, there was no significant interaction “condition × time” during TTE for RPE ($F_{1, 22} = 0.47$; $p = 0.5005$; $\eta^2p = 0.02$) and HR ($F_{1, 22} = 2.69$; $p = 0.1152$; $\eta^2p = 0.11$). (Fig. 3A and B).

During CLT-PRE, a significant main effect of time was observed for both RPE ($F_{1.4, 29.7} = 18.79$; $p < 0.0001$; $\eta^2p = 0.47$) and HR ($F_{2.3, 50.1} = 42.25$; $p < 0.0001$; $\eta^2p = 0.66$). However, no significant interaction “condition × time” was observed during CLT-PRE for RPE ($F_{5, 110} = 0.03$; $p = 0.9995$; $\eta^2p = 0.00$) and HR ($F_{5, 110} = 0.45$; $p = 0.8161$; $\eta^2p = 0.02$) (Fig. 4A and 4B).

During CLT-POST, a significant main effect of time was observed for both RPE ($F_{1, 22} = 15.76$; $p = 0.0007$; $\eta^2p = 0.42$) and HR ($F_{1, 22} = 67.33$; $p < 0.0001$; $\eta^2p = 0.75$). Moreover, a significant interaction “condition × time” was observed during CLT-POST for HR ($F_{1, 22} = 5.90$; $p = 0.0238$; $\eta^2p = 0.21$), but not for RPE ($F_{1, 22} = 0.05$; $p = 0.8181$; $\eta^2p = 0.00$). (Fig. 4C and 4D). No pairwise differences were found between conditions in CLT-POST for HR.

A significant main effect of time was observed for both MASK and control in T_{face} ($F_{1.8, 40.4} = 10.35$; $p = 0.0003$; $\eta^2p = 0.31$) as well as in T_{chest} ($F_{1.7, 36.6} = 20.96$; $p < 0.0001$; $\eta^2p = 0.49$). Moreover, significant interaction “condition × time” was observed for T_{face} ($F_{2, 44} = 36.93$; $p < 0.0001$; $\eta^2p = 0.63$) but not for T_{chest} ($F_{2, 44} = 0.96$; $p = 0.3895$; $\eta^2p = 0.04$). (Fig. 5A and B). Significant pairwise difference was found between conditions in T_{face} at post-treat ($p < 0.0001$).

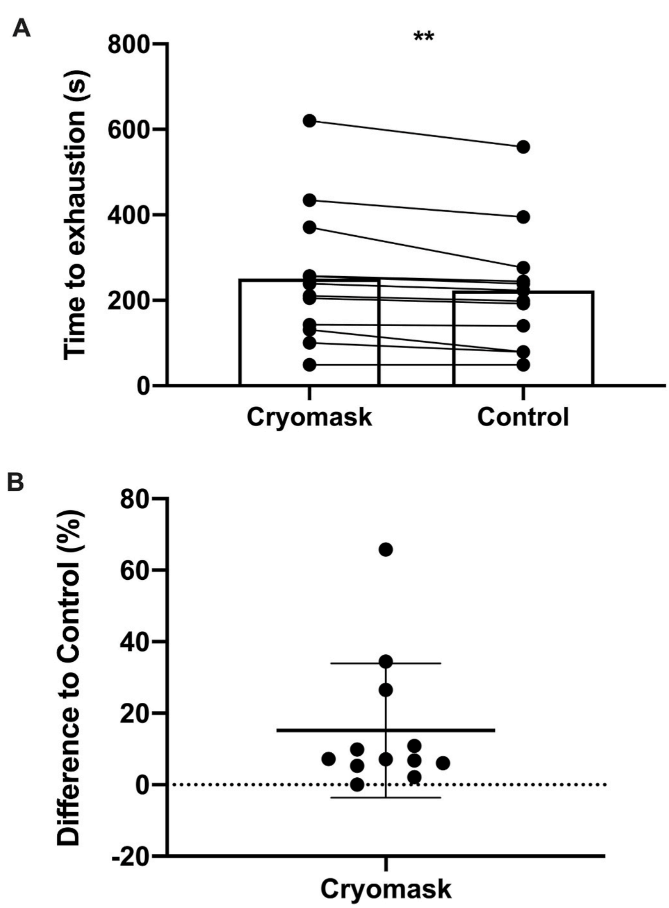

Fig. 2. A) Effects of the cryo-facial mask on time-to-exhaustion (TTE) test under stimulation (Cryomask) or control conditions. Significant difference between the two conditions: ***p < 0.01*. **B)** Results of TTE-test, expressed as percentage variations relative to the control.

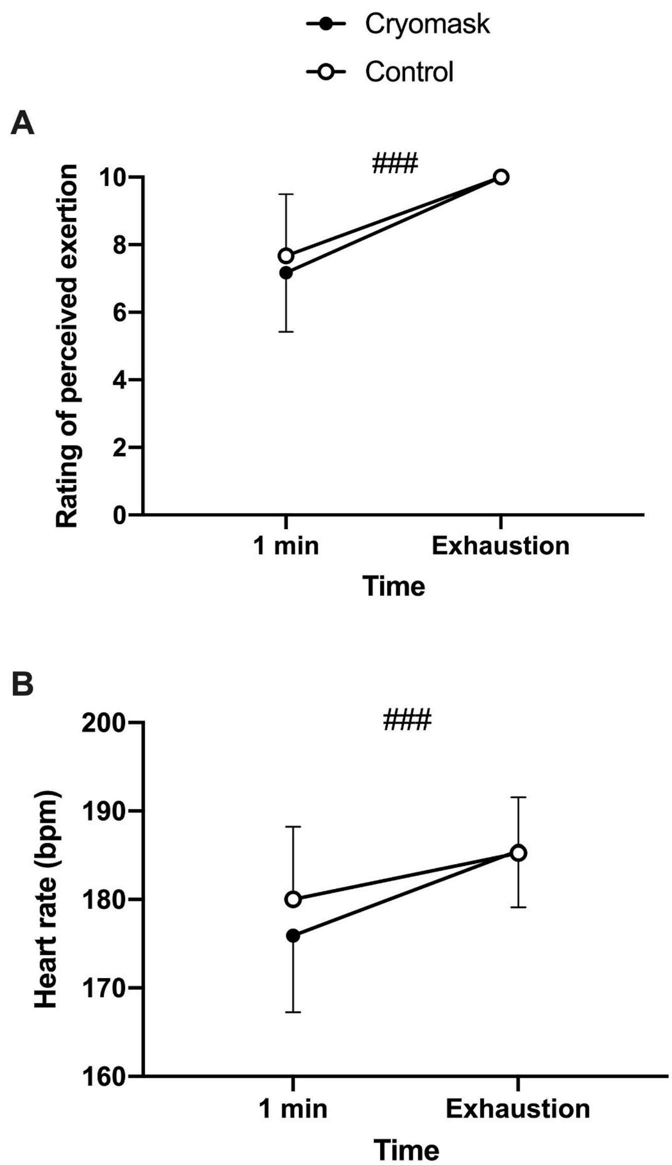

Fig. 3. Effects of the cryo-facial mask on ratings of perceived exertion (A) and heart rate (B) were measured 1 min upon commencement of the TTE-test and at exhaustion, under stimulation (Cryomask, black circles) or control (white circles) conditions. Significant main effect of time: *###p < 0.001.*

4. Discussion

In the present study, we aimed to examine the impact of a novel localized cryostimulation device, specifically the cryo-facial mask applicator, on running performance at moderate and high intensities within a moderate-temperature environment. The primary outcome of this study revealed that the use of the MASK led to a notable improvement in time to exhaustion at v$\dot{V}$O2peak when compared to the control condition. Specifically, the study demonstrated a substantial enhancement in TTE of approximately 13 % following the application of the cryo-facial mask compared to the control condition. Prior research has established the efficacy of precooling techniques in enhancing endurance performance. One common method is cryotherapy, involving the use of ice baths or cold packs to reduce body temperature. Furthermore,

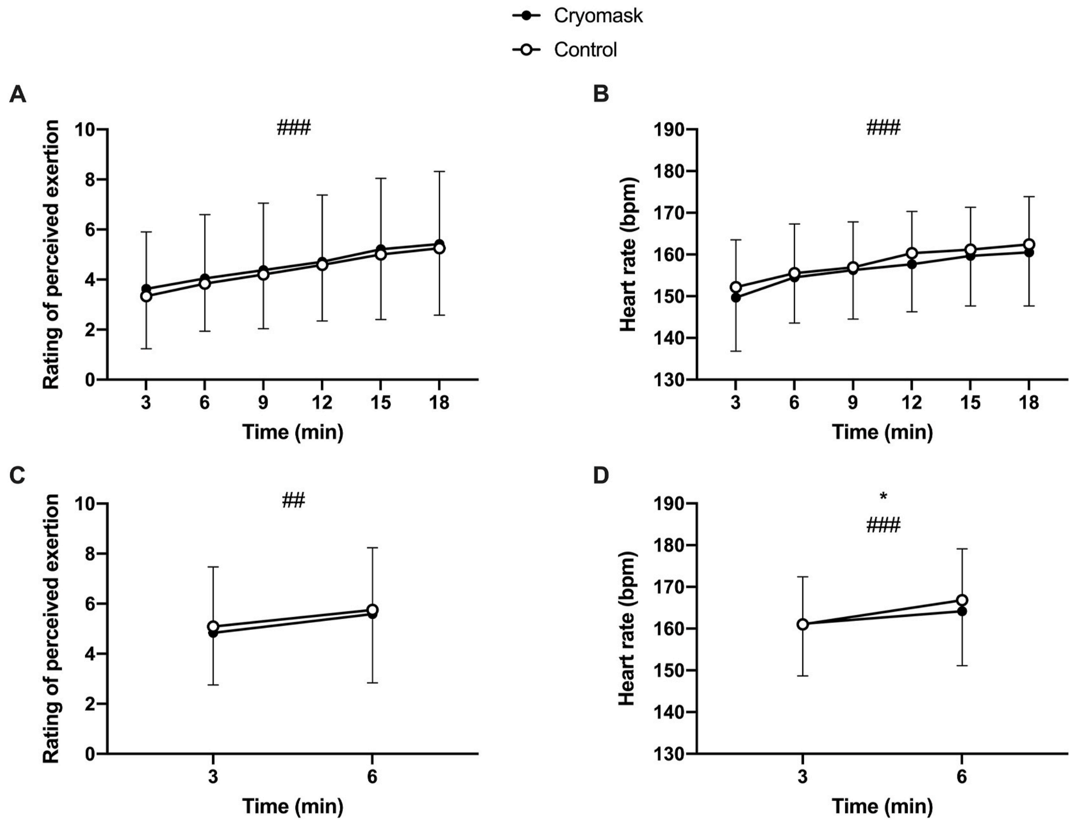

Fig. 4. Effects of the cryo-facial mask on ratings of perceived exertion and heart rate during the constant load trial before the treatment (A, B, respectively), and during constant load trial after the treatment (C, D, respectively), under stimulation (Cryomask, black circles) or control (white circles) conditions. Significant interaction "condition × time": **p < 0.05;* significant main effect of time: *##p < 0.01*, *###p < 0.001*.

evaporative cooling, facilitated by methods such as wetted clothing or misting, enhances heat dissipation through sweat evaporation, assisting in temperature regulation during exercise [21]. However, these studies have primarily focused on various precooling methods, and the specific impact of face cooling alone has rarely been investigated. Facial cooling, achieved applying soft-gel packs close to the skin, has been proven effective in enhancing endurance exercise in a population of healthy men who performed continuous ergometric cycle exercise by decreasing RPE values [22]. For instance, a recent study by Coelho et al. demonstrated that a 20-min head cooling intervention improved 5-km running performance in hot environment conditions among amateur runners [23]. In our study, the improvement in performance observed in a moderate-temperature environment, sparks interest in assessing its efficacy even in warm conditions [7]. This outcome is in line with previous studies on precooling strategies, which have consistently shown their effectiveness in improving performance by enhancing the body's heat storage capacity. By reducing the body's core and skin temperatures, precooling techniques help delay the onset of thermally-induced fatigue and optimize athletic performance [24]. These study results further support the notion that precooling strategies can be an effective approach to optimize performance in various sports and exercise settings. Our findings could be attributed to the cooling effect of the face, which resulted in a reduction in skin temperature. However, participants' thermal discomfort at the face was not assessed, potentially leading to a perception of a more favorable thermal environment. This, in turn, could enable athletes to perform at a higher level without the distraction of excessive heat. Instead, the ratings of perceived exertion values following the application of the cryo-facial mask, both during CLT-POST and at the beginning of TTE, did not show a significant difference, despite the absolute values being lower for the MASK condition. Furthermore, the cryo-facial mask treatment resulted in a non-significant reduction in heart rate during CLT-POST compared to the control condition. It is therefore debatable and open to criticism that the cryo-facial mask may have a beneficial impact on cardiovascular responses during exercise. Whether this potentially contributes to improved performance and reduced physiological strain remains uncertain. In fact, given the high coefficient of variation and the significance falling within the smallest worthwhile change, we acknowledge that these results may be attributed to chance. Further research is warranted to explore the underlying mechanisms and physiological implications behind these responses. Indeed, the combination of lower absolute RPE values and reductions in HR during CLT could provide a plausible explanation for the improved performance observed in the TTE test for the MASK condition. If so, the lower RPE values would suggest a reduced perception of effort and a lower subjective sense of exertion, indicating a potentially more comfortable and less fatiguing experience during exercise [25]. Additionally, the non-significant reduction in HR leaves open the possibility of decreased cardiovascular effort, which, in turn, may contribute to improved endurance and prolonged exercise duration. Taken together, these factors suggest that the cryo-facial mask treatment warrants further investigation to determine if it is associated with a more favorable physiological and perceptual state, enabling participants to sustain their effort for a longer duration during the TTE test.

The incorporation of the cryo-facial mask as a part of an athlete's pre-performance routine holds promise for enhancing sports performance. Importantly, the observed improvements were not influenced by the ambient temperature, as the laboratory environment was standardized to be thermoneutral. Future research should encourage athletes and practitioners to consider implementing facial precooling techniques as part of their training or competition preparations, particularly in situations where heat stress is a concern.

It is important to highlight that the cryo-facial mask utilized in this study was a novel device specifically designed to provide continuous

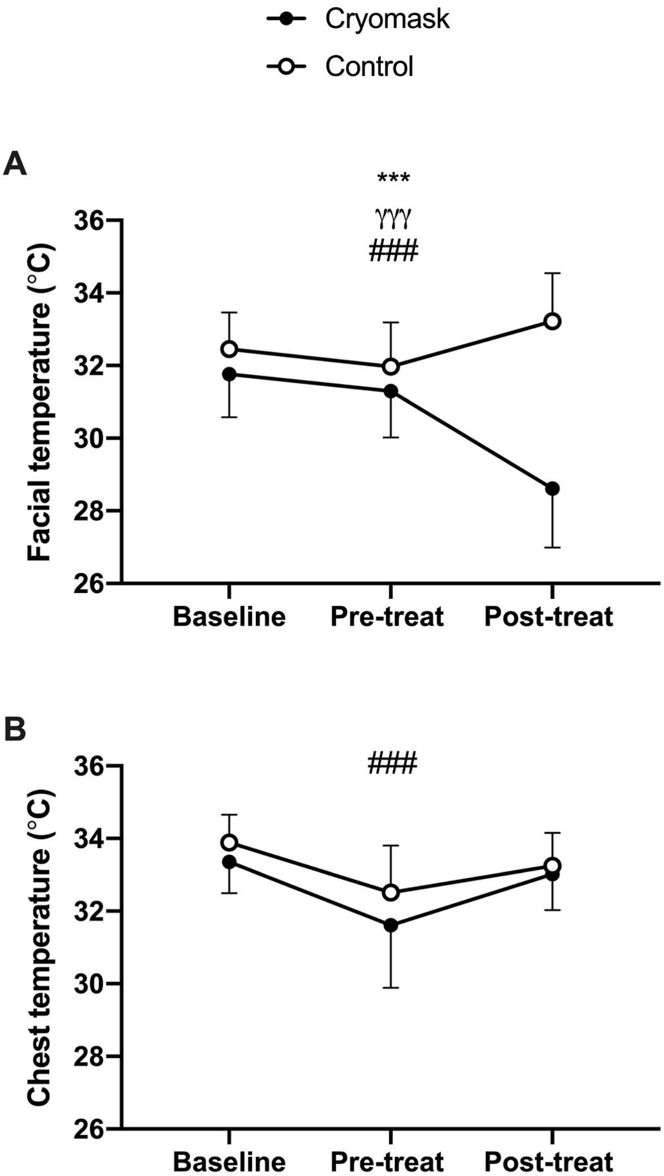

Fig. 5. Effects of the cryo-facial mask on the skin temperature under stimulation (Cryomask, black circles) or control (white circles) conditions. In detail, facial (A) and chest (B) skin temperatures were measured at three different time points: before CLT-PRE (Baseline), immediately after CLT-PRE (Pre-treat) and immediately after the intervention "control/MASK" (Post-treat). Significant interaction "condition × time": ****$p < 0.001$*; significant main effect of condition: γγγ $p < 0.001$; significant main effect of time: *###$p < 0.001$*.

high-velocity airflow. This unique feature allowed for a rapid reduction in facial temperature within a short duration of application (3 min). The ability of the cryo-facial mask to rapidly and effectively lower facial temperature is a significant advantage, as it facilitates the precooling process and enables athletes to incorporate it seamlessly into their training or competition routines. The efficiency and convenience of the cryo-facial mask make it a promising tool for enhancing performance in various sports and exercise contexts.

To the best of our knowledge, this is the first study to specifically investigate the effectiveness of facial precooling using a cryo-facial mask prior to a time to exhaustion test. This novel approach enriches the existing body of research on precooling strategies by highlighting the potential benefits of targeting the facial region. Importantly, our findings demonstrate that the cryo-facial mask is not only effective but also practical and convenient to use. The simplicity of the cryo-facial mask, requiring minimal installation and operating efforts, makes it an attractive option for athletes, coaches, and practitioners seeking efficient and accessible precooling methods. By offering a user-friendly solution, the cryo-facial mask has the potential to be easily incorporated into pre-performance routines, providing athletes with an effective means of optimizing their performance. Furthermore, it is worth noting that no side effects were reported by the participants following the cryo-facial mask treatment. The favorable safety profile adds to the overall appeal and feasibility of incorporating the cryo-facial mask into training and competition routines.

Our study has several limitations. First of all, we did not measure the core temperature of the participants. Monitoring core temperature would have provided valuable insights into the physiological mechanisms underlying facial precooling. New studies may implement measurements of both skin and core temperature to gain a more comprehensive understanding of the thermoregulatory responses associated with facial precooling. Lastly, we did not measure perceptual responses such as thermal sensation and thermal comfort or discomfort, which could contribute to examining the relationship between these factors and exercise performance and changes in RPE values. This additional data would enhance our understanding of the physiological effects of facial precooling and shed lights into its mechanisms of action. Finally, the implications for training should be considered within the context of the parameters studied. Future research is necessary to explore how these findings may apply to different types of exercise, with varying intensities and durations, to ensure a comprehensive understanding of their impact on training and performance. Additionally, further studies are needed to elucidate the underlying mechanisms by which localized cryostimulation devices, such as the cryo-facial mask, impact perceptual, physiological responses, as well as exercise performance. Investigating the specific physiological and thermoregulatory changes induced by facial precooling could help clarify how performance enhancements occur. Moreover, examining the potential long-term effects, optimal application protocols, and the comparative effectiveness of different precooling strategies will contribute to refining the practical implementation of facial precooling in various athletic settings. Continued research in this area will enhance our knowledge and evidence-based guidelines for maximizing the benefits of facial precooling in sports and exercise.

5. Conclusion

Our findings provide support for the effectiveness of the cryo-facial mask as a precooling strategy to enhance exercise performance in trained endurance runners. The significant improvements observed in time to exhaustion, despite absence of significant differences in perceived exertion and heart rate, indicate a likely positive impact of facial precooling on endurance performance. These results highlight the potential practical application of the cryo-facial mask as a valuable tool in the training and competition routines of endurance runners. By incorporating the cryo-facial mask as a precooling strategy, athletes may be able to optimize their performance and achieve better outcomes in endurance events.

CRediT authorship contribution statement

Massimo De Nardi: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Luca Filipas:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Simone Di Gennaro:** Methodology, Investigation, Data curation. **Silvia Allemano:** Investigation. **Gabriele Gallo:** Methodology, Investigation. **Andrea Meloni:** Validation, Investigation. **Lucio Della Guardia:** Writing – review & editing, Investigation. **Livio Luzi:** Validation, Supervision, Conceptualization. **Antonio La Torre:** Validation, Supervision. **Roberto Codella:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The mask was purchased on a voluntary basis; the manufacturer was utterly unaware of this proof-of-concept study.

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References

[1] Z.J. Schlader, S.R. Stannard, T. Mundel, Exercise and heat stress: performance, fatigue and exhaustion–a hot topic, Br. J. Sports Med. 45 (1) (2011) 3–5, https://doi.org/10.1136/bjsm.2009.063024.

[2] L. Nybo, Hyperthermia and fatigue, J. Appl. Physiol. 104 (3) (2008) 871–878, https://doi.org/10.1152/japplphysiol.00910.2007.

[3] J. Folland, D. Rowlands, R. Thorp, A. Walmsley, Leg heating and cooling influences running stride parameters but not running economy, Int. J. Sports Med. 27 (10) (2006) 771–779, https://doi.org/10.1055/s-2005-872963.

[4] C.J. Stevens, A. Kittel, D.V. Sculley, R. Callister, L. Taylor, B.J. Dascombe, Running performance in the heat is improved by similar magnitude with pre-exercise cold-water immersion and mid-exercise facial water spray, J. Sports Sci. 35 (8) (2017) 798–805, https://doi.org/10.1080/02640414.2016.1192294.

[5] M. Ross, C. Abbiss, P. Laursen, D. Martin, L. Burke, Precooling methods and their effects on athletic performance, Sports Med. 43 (3) (2013) 207–225, https://doi.org/10.1007/s40279-012-0014-9.

[6] C.C.W.G. Bongers, M.T.E. Hopman, T.M.H. Eijsvogels, Cooling interventions for athletes: an overview of effectiveness, physiological mechanisms, and practical considerations, Temperature 4 (1) (2017) 60–78, https://doi.org/10.1080/23328940.2016.1277003.

[7] M. Wegmann, O. Faude, W. Poppendieck, A. Hecksteden, M. Fröhlich, T. Meyer, Pre-cooling and sports performance: a meta-analytical review, Sports Med. 42 (7) (2012) 545–564, https://doi.org/10.2165/11630550-000000000-00000.

[8] F.D. Legrand, B. Dugué, J. Costello, et al., Evaluating safety risks of whole-body cryotherapy/cryostimulation (WBC): a scoping review from an international consortium, Eur. J. Med. Res. 28 (1) (2023), https://doi.org/10.1186/s40001-023-01385-z.

[9] M. De Nardi, C. Facheris, P. Ruggeri, A. La Torre, R. Codella, High-impact routines to ameliorate trunk and lower limbs flexibility in women, Int. J. Sports Med. (2020), https://doi.org/10.1055/a-1119-7902. Published online.

[10] M. De Nardi, S. Silvani, P. Ruggeri, L. Luzi, A. La Torre, R. Codella, Local cryostimulation acutely preserves maximum isometric handgrip strength following fatigue in young women, Cryobiology 87 (2019) 40–46, https://doi.org/10.1016/j.cryobiol.2019.03.002.

[11] Y. Cao, T.-H. Lei, F. Wang, B. Yang, T. Mündel, Head, face and neck cooling as per-cooling (cooling during exercise) modalities to improve exercise performance in the heat: a narrative review and practical applications, Sport Med - Open 8 (1) (2022) 16, https://doi.org/10.1186/s40798-022-00411-4.

[12] A.K.A. McKay, T. Stellingwerff, E.S. Smith, D.T. Martin, I. Mujika, V.L. Goosey-Tolfrey, J. Sheppard, L.M. Burke, Defining training and performance caliber: a participant classification framework, Int. J. Sports Physiol. Perform. 17 (2022) 317–331, https://doi.org/10.1123/ijspp.2021-0451.

[13] N. Williams, The Borg rating of perceived exertion (RPE) scale, Occup Med (Chic Ill) 67 (5) (2017) 404–405, https://doi.org/10.1093/occmed/kqx063.

[14] G. Borg, Borg's Perceived Exertion and Pain Scales, Hum Kinet, 1998. Published online.

[15] R.K. Binder, M. Wonisch, U. Corra, et al., Methodological approach to the first and second lactate threshold in incremental cardiopulmonary exercise testing, Eur J Prev Cardiol (2008), https://doi.org/10.1097/HJR.0b013e328304fed4. Published online.

[16] V.L. Billat, D.W. Hill, J. Pinoteau, B. Petit, J.-P. Koralsztein, Effect of protocol on determination of velocity at VO 2 max and on its time to exhaustion, Arch. Physiol. Biochem. 104 (3) (1996) 313–321, https://doi.org/10.1076/apab.104.3.313.12908.

[17] D.G. Moreira, J.T. Costello, C.J. Brito, et al., Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature, J. Therm. Biol. 69 (2017) 155–162, https://doi.org/10.1016/j.jtherbio.2017.07.006.

[18] M. De Nardi, S. Allemano, A. Bisio, et al., Thermal responses induced by nitrogen and forced convection based partial-body cryostimulation, J. Therm. Biol. 115 (2023) 103620, https://doi.org/10.1016/j.jtherbio.2023.103620.

[19] R. Bakeman, Recommended effect size statistics for repeated measures designs, Behav. Res. Methods (2005), https://doi.org/10.3758/BF03192707. Published online.

[20] J. Cohen, Statistical Power Analysis for the Behavioral Sciences, Routledge, 2013, https://doi.org/10.4324/9780203771587.

[21] A. Ruddock, B. Robbins, G. Tew, L. Bourke, A. Purvis, Practical cooling strategies during continuous exercise in hot environments: a systematic review and meta-analysis, Sports Med. 47 (3) (2017) 517–532, https://doi.org/10.1007/s40279-016-0592-z.

[22] T. Miyazawa, M. Mizutani, J.P. Sheahan, D. Ichikawa, Intermittent face cooling reduces perceived exertion during exercise in a hot environment, J. Physiol. Anthropol. 40 (1) (2021) 12, https://doi.org/10.1186/s40101-021-00262-0.

[23] L.G.M. Coelho, J.B. Ferreira-Júnior, T.B. Williams, et al., Head pre-cooling improves 5-km time-trial performance in male amateur runners in the heat, Scand. J. Med. Sci. Sports 31 (9) (2021) 1753–1763, https://doi.org/10.1111/sms.13985.

[24] W. Zhang, S. Ren, X. Zheng, Effect of 3 min whole-body and lower limb cold water immersion on subsequent performance of agility, sprint, and intermittent endurance exercise, Front. Physiol. 13 (2022), https://doi.org/10.3389/fphys.2022.981773.

[25] R. Eston, Use of ratings of perceived exertion in sports, Int. J. Sports Physiol. Perform. 7 (2) (2012) 175–182, https://doi.org/10.1123/ijspp.7.2.175.