Cooling during Exercise in Temperate Conditions: Impact on Performance and Thermoregulation

Authors T. M. H. Eijsvogels[1, 2], C. C. W. G. Bongers[1], M. T. W. Veltmeijer[1], M. H. Moen[3], M. Hopman[1]

Affiliations
[1] Department of Physiology, Radboud University Medical Center, Nijmegen, The Netherlands
[2] Henry Low Heart Center, Department of Cardiology, Hartford Hospital, Hartford, Connecticut, USA
[3] NOC*NSF, medical staff, Papendal, The Netherlands

Key words
- cooling vest
- core body temperature
- endurance exercise
- athletes
- time trial
- precooling

Abstract

Exercise-induced increase in core body temperature may lead to the development of hyperthermia (>40.0 °C) and/or decreased performance levels. This study examined the effects of wearing a cooling vest during a 5-km time trial on thermoregulatory responses and performance. 10 male masters athletes (42 ± 10 years) performed a 5-km time trial on a motorized treadmill in a climate chamber (25 °C, 55 % relative humidity) with and without a cooling vest. Split times, heart rate, core-, skin- and cooling vest temperature were measured every 500 m. Subjects also rated thermal comfort and level of perceived exertion. The cooling vest significantly decreased heart rate ($p < 0.05$), decreased skin temperature ($p < 0.001$) and improved thermal comfort ($p < 0.005$) during the time trial. Time to finish the 5-km time trial and pacing strategy did not differ between the control (1 246 ± 96 s) and cooling vest condition (1 254 ± 98 s, $p = 0.85$). Additionally, thermoregulatory responses, maximum core body temperature and level of perceived exertion were not different across conditions ($p = 0.85$, $p = 0.49$, $p = 0.11$, respectively). In conclusion, we demonstrated that wearing a cooling vest during exercise improves thermal comfort but does not enhance performance or decrease core body temperature in male masters athletes under temperate ambient conditions.

Introduction

The oxidation of substrates during running exercise results in muscle power (~20 %) and heat production (~80 %) [4, 8]. The increased metabolic heat production usually exceeds the maximal capacity of heat dissipation [16], which results in a rise in core body temperature (T_c). Accordingly, hyperthermia (T_c > 40.0 °C) may develop [1, 16], which could lead to decreased performance levels and/or the development of heat related illnesses [1, 20, 25]. Consequently, any attempt to delay the rise in core body temperature during exercise may enhance exercise performance levels in athletes, and prevent them from developing heat-related symptoms [3, 5, 27].

In the last decade many cooling techniques were evaluated in athletes, with particular interest in precooling strategies [21]. Precooling increases the heat storage capacity of the body which enables an athlete to perform more work before reaching limiting T_c levels, thus delaying the onset of fatigue due to hyperthermia [27]. Precooling with cold air, cold water immersion, cooling vests, ice slurry ingestion and combinations of these techniques effectively reduced T_c and increased athletic performance levels in previous studies [18, 20, 25]. However, some of these cooling strategies (i. e., cold air/cold water immersion) may be impractical for use in competitive settings due to the need for specialized equipment, poor transportability to a field setting, athlete discomfort and costs [18, 20].

Cooling during exercise represents an alternative strategy to improve exercise performance. Previous studies indicated that local cooling of a small surface area (i. e., hand or neck) during exercise improved cycling and running performance by 6–13.5 % [10, 29]. Cooling a larger body surface, such as using a cooling vest, may result in a further increase of exercise performance levels. While previous cooling vests were uncomfortable and too heavy for athletes [2, 32], recent developments have resulted in a new generation light-weight cooling vest (HyperKewl™) suitable for cooling during exercise. However, evidence of the benefits of wearing cooling vest is currently restricted to precooling studies only [21]. Therefore, the purpose of this study was to determine the effects of wearing a cooling vest during a

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Correspondence
Dr. Thijs M. H. Eijsvogels
Physiology (392)
Radboud University Medical Centre
P.O. Box 9101
Nijmegen 6500 HB
Netherlands
Tel.: +31/24/3613 674
Fax: +31/24/3616 413
Thijs.Eijsvogels@Radboudumc.nl

Table 1 Subject characteristics of the 10 athletes included in the study.

Variable	Subjects (n=10)
age (years)	42 ± 10
height (cm)	182 ± 5
weight (kg)	73.6 ± 6.5
BMI (kg/m²)	22.2 ± 1.4
personal best 5-km (min:s)	18:10 ± 00:54

5-km treadmill time trial on performance and thermoregulatory responses in masters athletes. We hypothesized that a cooling vest is effective in limiting or delaying the increase in T_c, and subsequently may improve the time to finish the 5-km time trial. Interestingly, current regulations of the International Association of Athletics Federations (IAAF) allow the use of a cooling vest during race conditions [12].

Materials & Methods

Subjects

10 male athletes volunteered to participate in this study (▶ **Table 1**). Participants were eligible if they were ≥18 years and had a 5 km race personal best ≤20 min. Exclusion criteria were based on the use of the temperature pill: I) body weight < 36.5 kg, II) implanted electro-medical device, III) gastro-intestinal disease, IV) a scheduled MRI scan. The study was approved by the Medical Ethical Committee of the Radboud University Medical Centre (study-id: 2011/546), and all participants gave written informed consent prior to participation in the study. All procedures were in accordance with the ethical standards of IJSM [9].

Study design

In this randomized crossover study, participants were invited to 4 study visits. First, participants were medically screened to determine whether they met the inclusion criteria. During the second visit, all participants performed a habituation time trial: participants performed the entire protocol and were able to get accustomed to running on a treadmill in the climate chamber (B-cat, Tiel, the Netherlands). Environmental conditions were controlled at an ambient temperature of 25 °C, relative humidity of 55 % and a wind velocity of 3 m/s, which is equal to an indoor WBGT index of 25 °C. The experimental conditions of the third and fourth visit were randomized to an intervention (cooling vest) or control time trial. All participants had a minimum of 5 days of recovery between each visit. To eliminate any bias, participants were informed that the study aimed to investigate whether running in a cooling vest either improved performances because of cooling, or decreased performances because of the added weight of the vest [27]. All visits were scheduled between 9:00 a.m. and 6:00 p.m. To minimize the effects of the circadian rhythm on the T_c and heart rate [2,34], the time trial tests were performed at the same time of the day for each subject.

During all sessions, participants were instructed to wear the same clothes, which consisted of a pair of shorts and a dry-fit running shirt. Participants were allowed to eat and drink ad libitum before exercise, while they registered all fluid intake 24 h before the measurement. Furthermore, participants were instructed to eat the same diet before each time trial to minimize the effect of nutrition. In preparation for all time trials, participants were not allowed to perform strenuous exercise or consume alcohol or caffeine 24 h before testing as this may impact performance.

Time trial protocol

The 5-km time trial protocol is an effective method to demonstrate the effect of cooling interventions [2,11]. The high exercise intensity ensures a rapid increase in T_c which may impact performance and can potentially be counteracted by a cooling vest. Upon arrival in the climate chamber, body mass and baseline lactate level were measured. Level of perceived exertion and thermal comfort were scored. T_c, skin temperature and heart rate recorders were applied, and data were obtained at baseline and every 500 m during the time trial. The treadmill (Technogym excite med L1, Technogym, United Kingdom) was set at a 1 % grade, to mimic conditions of outdoor road running [15]. Thereafter, participants performed a standardized 12-min warm-up: speed was first increased from 6 to 14 km/h (2 km/h steps per 2 m), followed by a cooling down at 10 km/h and 6 km/h (2 min each). Thereafter participants had 5 min for stretching and resting before the start of the time trial. In the intervention condition, the cooling vest was removed from the refrigerator and applied to the athlete 1 min before the start of the time trial. During the 5-km time trial, running speed was controlled by the subject. Information about running speed and split times was blinded for participants, while completed distance was continuously displayed to assist with pacing. To obtain maximum performance, runners were verbally encouraged every 500 m. Level of perceived exertion and thermal comfort were scored every km. Immediately following completion of the time trial, body mass was determined again. Capillary lactate level was measured 2 min after completion of the 5-km time trial.

Cooling vest

The cooling vest (HyperKewl™, TechNiche, Vista, California, USA) was worn over the dry-fit running shirt and covered the major part of the participants' trunk. The cooling surface area of the vest was 2 258 cm². The day before each time trial, the cooling vest was activated according manufacturer instructions: 1) soak in water for 2 min, 2) squeeze excess water, 3) dry for 2 h at room temperature. The cooling vest was then placed in a refrigerator (6.0 °C ± 0.5 °C, > 8 h) and ready to use. The weight of the activated cooling vest was 485 ± 85 g.

Measurements

Split and finish times: Time to complete the 5-km time trial (finish time) was our primary outcome parameter. Additionally, 500-m split times were registered to detect potential differences in pacing strategy between the cooling vest and control condition.

Heart rate (HR): HR was measured at 15-s intervals using a Polar RS 400 system (Polar Electro Oy, Kempele, Finland). The highest HR value was presented as the HR_{max}.

Core body temperature (T_c): T_c was measured using a CorTemp™ system (HQ Inc., Florida, USA), which is safe and reliable [7]. Participants ingested an individually calibrated telemetric temperature sensor at least 5 h preceding the experiment to avoid any interaction with fluid ingestion [35]. T_c was measured at 20-s intervals using an external recorder worn in a pouch around the waist.

Skin temperature (T_{sk}): T_{sk} was assessed using wireless temperature recorders (iButton DS1922L, Dallas Semiconductor Corp, USA) set to acquire temperature samples at 20-s intervals with a resolution of 0.0625 °C [26, 31]. The temperature recorders were attached to the skin using Tegaderm Film (Tegaderm, Neuss, Germany). T_{sk} was measured at 8 distinct locations according to the ISO-9886 standard [13]. An index of T_{sk} mean was calculated as the weighted average of the 8 sites for each individual (▶ **Fig. 1**) [13].

Trunk temperature: We added 2 iButton sensors to assess the effect of the cooling vest more precisely. The average value of the 4 trunk iButtons was considered as the T_{sk} trunk (▶ **Fig. 1**) [13]. Differences between the T_c and T_{sk} trunk were expressed as the core-to-trunk temperature gradient and calculated by subtracting these values.

Cooling vest temperature: 4 iButtons were placed in the inside and outside fabric layers of the cooling vest (▶ **Fig. 1**). Cooling vest temperature was calculated using the average of these 4 locations. Cooling vest to T_{sk} trunk gradient was calculated by subtracting both values.

Blood lactate level: Capillary blood lactate levels were measured with an Accutrend plus GCT Cobas analyzer (Roche Diagnostics Limited, West Sussex, England). The blood lactate level was measured prior to warm-up, and 2 min after finishing the 5-km time trial.

Subjective parameters: Thermal comfort was assessed on a 7-point category scale, in which -3 was corresponding with very cold and +3 was very hot [6]. The level of perceived exertion was measured by the 10-point BORG category scale, in which 0 corresponded to rest and 10 to maximal exertion [19]. Both subjective parameters were scored every kilometer during the time trial.

Fluid balance: The relative change in body mass (in %) between the measurement at baseline and directly after completion of the 5-km time trial was calculated, and dehydration was defined as a body mass loss of 2 % or more [23, 24].

Data analysis

All values were presented as mean ± standard deviation, unless indicated otherwise. Statistical analyses were performed using SPSS (IBM SPSS version 20.0, Armonk, NY, USA.), and the level of significance was set at $p < 0.05$. To assess differences in exercise characteristics between the control and cooling vest condition, a paired Student's T-Test was performed. To analyze differences over time during the 5-km time trial, and to determine whether physiological responses differed between the control and cooling vest condition we performed a 2-way repeated measures ANOVA. Our statistical model included distance and condition (control or cooling vest) as intra-subject factors.

Results

Subject and exercise characteristics

All participants successfully completed the 5-km time trials, while there were no differences in ambient conditions (temperature: $p = 0.19$, humidity: $p = 0.32$) between the cooling vest and control condition. The cooling vest significantly decreased in weight after the time trial (−50 g, $p = 0.003$). Fluid loss was not

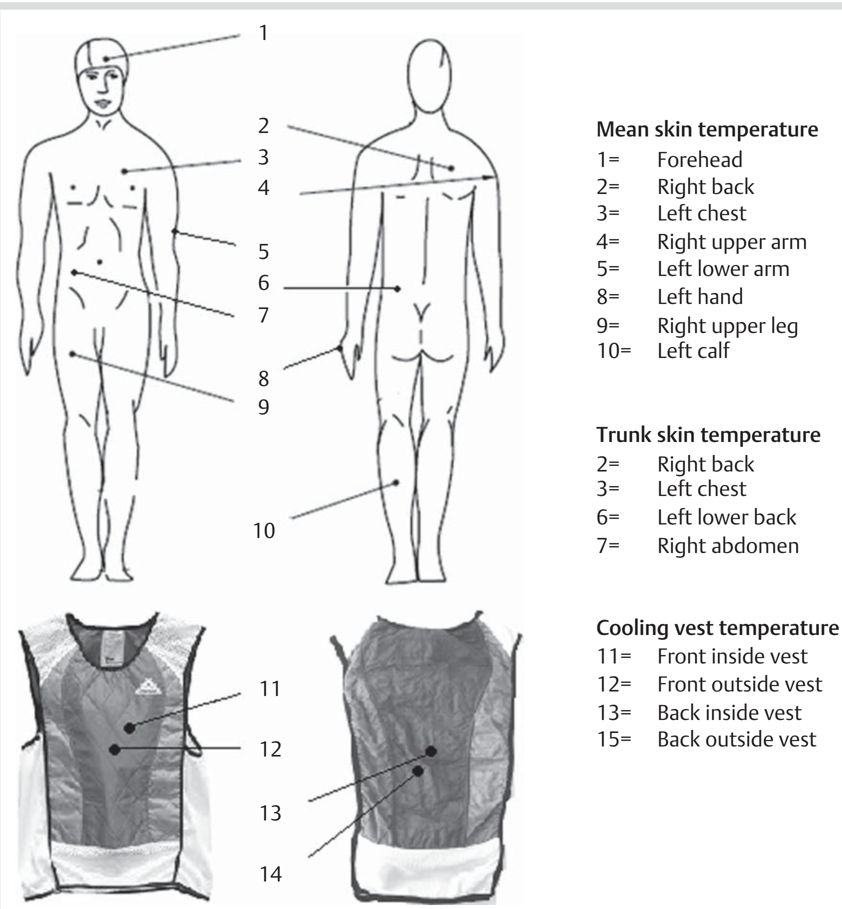

Fig. 1 Overview of (anatomical) locations that were used to place the wireless iButtons sensors to measure the mean skin temperature, trunk skin temperature and cooling vest temperature.

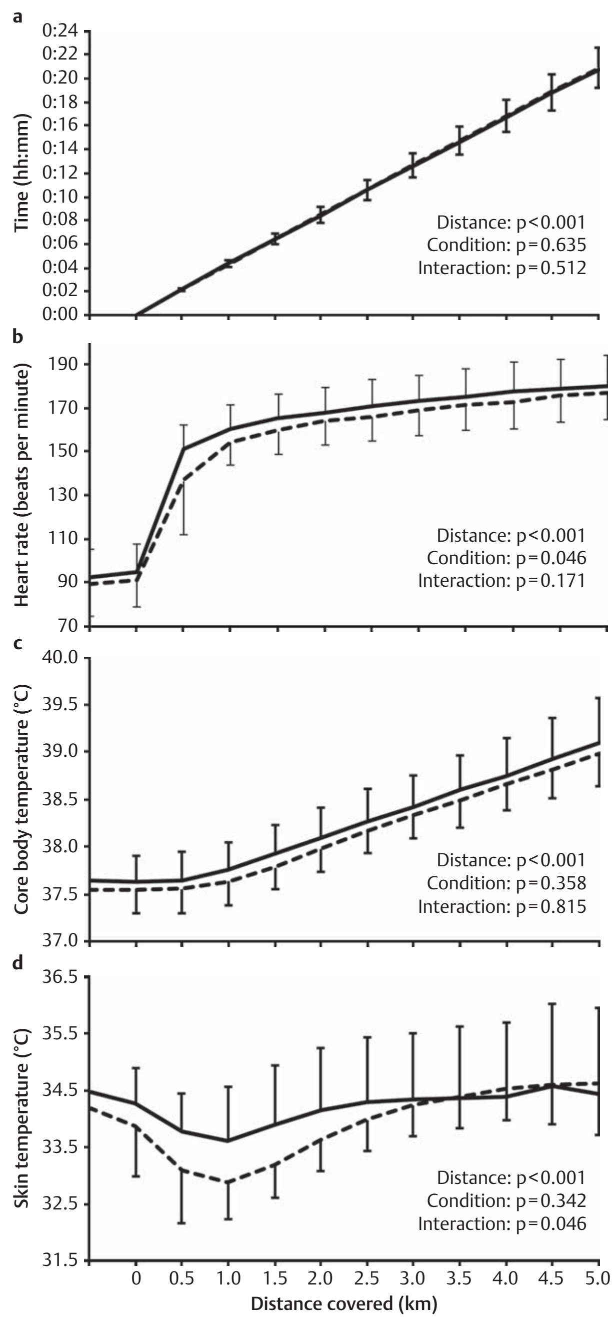

Fig. 2 Performance levels, heart rate and thermoregulatory responses, in the control (solid line) and the cooling vest condition (dashed line) during the 5-km time trial. **a** Split times did not differ between conditions (p = 0.635), while the pacing strategy was comparable (interaction; p = 0.512). **b** Heart rate increased significantly during both trials (p < 0.001). However, heart rate was significantly lower in the cooling vest compared to control condition (p = 0.046), despite a comparable course in heart rate over time (interaction; p = 0.171). **c** A significant increase in core body temperature was observed (p < 0.001), with a comparable change over time across both conditions (p = 0.815). **d** Skin temperature changed significantly throughout both conditions (p < 0.001), with lower temperatures during the first half of the time trial in the cooling vest condition (p = 0.046). The error bars represent the SD.

different between conditions (p = 0.19), with a body mass loss of −0.99 ± 0.23 % in the control condition and −0.96 ± 0.24 % in the cooling vest condition. Blood lactate levels significantly increased from baseline (2.2 ± 0.5 mmol/L) to post-exercise (8.8 ± 2.1 mmol/L, P < 0.001), with no differences in the responses between both conditions (p = 0.17).

Time trial performance and heart rate

The 5-km finish times were 1 246 ± 96 s (20 min and 46 s) and 1 254 ± 98 s (20 min and 54 s) for the control and cooling vest condition, respectively, and did not differ statistically (p = 0.86) (▶ **Fig. 2a**). Furthermore, pacing strategy (expressed by split times) during the 5-km time trial was comparable across conditions (p = 0.51). HR did not differ between conditions at baseline (p = 0.96) and increased significantly during the 5-km time trial in both conditions (p < 0.001). However, the average HR was significantly lower in the cooling vest compared to the control condition (▶ **Fig. 2b**, p = 0.046). HR_{max} was 180 ± 9 beats per min in the control condition and 177 ± 9 beats per min in the cooling condition and did not differ statistically (p = 0.11).

Core body temperature and skin temperature

Baseline T_c was 37.6 ± 0.3 °C during the control condition and 37.5 ± 0.2 °C during the cooling condition, and did not differ (p = 0.18). T_c increased significantly during the 5-km time trial (p < 0.001), with a comparable response across conditions (▶ **Fig. 2c**, p = 0.82). Additionally, the magnitude of the increase in T_c (p = 0.85) and maximum T_c (p = 0.49) did not differ between the control (1.5 ± 0.4 °C and 39.1 ± 0.5 °C, respectively) and cooling vest condition (1.4 ± 0.4 °C and 39.0 ± 0.3 °C, respectively). T_{sk} was comparable between the control and cooling vest condition (p = 0.13) at baseline. Subsequently, T_{sk} changed significantly during the 5-km time trial (p < 0.001), with significantly lower values in the cooling vest compared to the control condition (▶ **Fig. 2d**, p = 0.046).

Trunk and cooling vest temperature

T_{sk} trunk was relatively stable in the control condition during the 5-km time trial, while a significant decrease was observed in the cooling vest condition (▶ **Fig. 3a**, p < 0.001). Additionally, the T_{sk} trunk to T_c temperature gradient was higher in the cooling vest compared to the control condition (▶ **Fig. 3b**, p = 0.004). Initial cooling vest temperature was 9.7 ± 2.3 °C and increased significantly during the 5-km time trial (▶ **Fig. 3c**, p < 0.001). The cooling vest to T_{sk} trunk gradient showed an opposite curve with a maximal difference of 24.6 ± 2.2 °C before the start, and 6.2 ± 1.2 °C upon completion of the time trial (▶ **Fig. 3d**).

Subjective parameters

The thermal comfort score was neutral at baseline, and significantly increased during the 5-km time trial (▶ **Fig. 4a**, p < 0.001). While the change in thermal comfort score was comparable across groups (p = 0.57), participants reported an overall lower score in the cooling vest condition (p = 0.003). Additionally, level of perceived exertion scores increased significantly during the 5-km time trial (▶ **Fig. 4b**, p < 0.001). However, absolute level of perceived exertion scores (p = 0.30) and the change over time (p = 0.11) did not differ across conditions.

Discussion

This is the first study that assessed the effects of wearing a cooling vest during a 5-km time trial on performance levels and thermoregulatory responses. We found that wearing the cooling vest during exercise resulted in a significant decrease in skin and

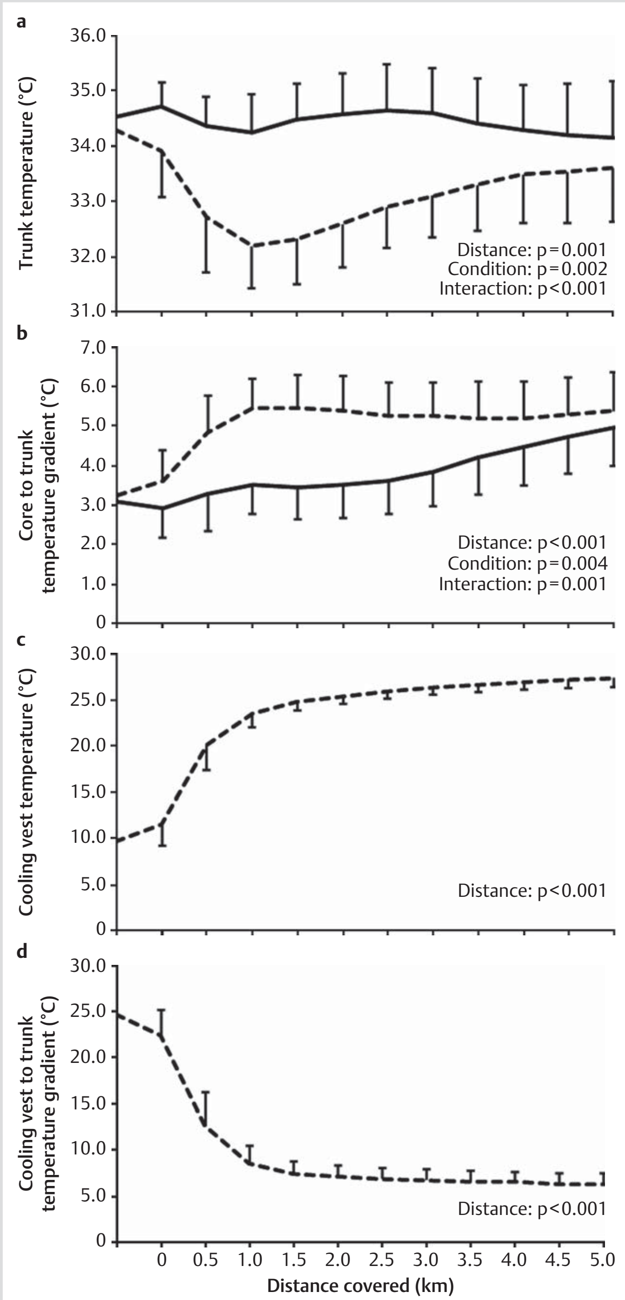

Fig. 3 Trunk skin and cooling vest temperatures in the control (solid line) and the cooling vest condition (dashed line) during the 5-km time trial. **a** The change in trunk skin temperature was significantly different between conditions ($p<0.001$), with a marked decrease in temperature after the cooling vest was placed on the athlete ($p=0.001$). **b** Additionally, the core body to trunk skin temperature gradient demonstrated a different course over time between the conditions ($p=0.001$), with higher values in the cool vest condition ($p=0.004$). **c** Cooling vest temperature significantly increased during the time trial ($p<0.001$), while the **d** cooling vest to trunk skin temperature gradient showed an opposite response ($p<0.001$) with a value of 6.2 °C at the end of the test. The error bars represent the SD.

trunk temperature, and an improved thermal comfort in masters athletes. Although the cooling vest resulted in a significantly lower HR, it did not improve the time to finish the 5-km time trial or affect T_c responses. These results suggest that wearing a cooling vest improves the comfort of masters athletes while running in ambient conditions of 25 °C, but does not impact performance or T_c.

The use of a cooling vest to improve performance levels resulted in contradictory findings in precooling studies. While some studies found an improved time trial performance or exercise time until exhaustion [2,30], others reported no difference between the cooling vest and control condition [27]. To our knowledge, we are the first to apply a light-weight cooling vest during running exercise in masters athletes. Despite a clear impact of the cooling vest on HR, T_{sk} and T_{sk} trunk, the split times and finish time did not differ across conditions. A potential explanation for these findings may relate to the maximum T_c of 39.1 °C that was observed. Previous studies suggested that exercise performance may be limited at a T_c of 40 °C or higher [18,20,25]. Since our masters athletes did not reach the critical T_c threshold, they may therefore not have suffered from performance loss. Alternatively, the anticipatory hypothesis suggests that not peak T_c but the rate of increase in T_c is the limiting factor for performance decrement [20,28]. Although participants demonstrated a substantial T_c increase in this study, the cooling vest did not interact with T_c changes over time, potentially resulting in a comparable performance level in both conditions. Finally, fluid balance may also impact performance [22]. However, since participants demonstrated a similar fluid loss in the control and cooling vest condition this explanation can be excluded. In summary, 1) a limited peak T_c or 2) a comparable rise in T_c but 3) not the fluid balance, may have contributed to the absence of differences in performance between the control and cooling vest condition.

An alternative explanation for the comparable performance levels can be found in the cooling capacity of the vest. Our evaporative vest had a baseline temperature of 9.7 °C and a trunk to vest temperature gradient of 24.6 °C before the vest was placed on the athlete. However, after participants covered only 1 km of the time trial, the vest temperature increased to 23.6 °C and the gradient decreased to 8.6 °C (**Fig. 3**). Despite cooling vest temperature remaining lower than T_{sk}, heat transfer was limited during this phase. These findings are reinforced by the HR of the masters athletes. Differences between conditions were great during this first km of the time trial (**Fig. 2b**), but attenuated during the remainder of the test. A stronger cooling capacity of the vest may have prevented this. In fact, studies that used an ice-vest found a large effect on performance and thermoregulatory responses [3,17,33]. However, the ice vest (1 650 g) is substantially heavier than an evaporative vest [3]. Such heavy ice vests are therefore useful for precooling but inappropriate for cooling during exercise. Although the weight of our vest was low (489 g), our data suggest a limited cooling capacity to significantly impact T_c. Future studies should therefore investigate the optimal relationship between cooling capacity and weight of the vest to ensure maximal performance benefit for athletes during exercise.

Another factor that could contribute to our findings is the ambient condition under which the masters athletes had to perform the 5-km time trial. We chose a climate with an indoor WBGT index of 25 °C. Although solar radiation cannot be simulated in a climatic chamber, we believe that these circumstances represent the ambient conditions frequently present during mass participation running events. These conditions can be classified as moderate/temperate [1], and most studies that investigate the effects of cooling are therefore performed in ambient temperatures of 30 °C or higher [2,17,30]. Although the latter race set-

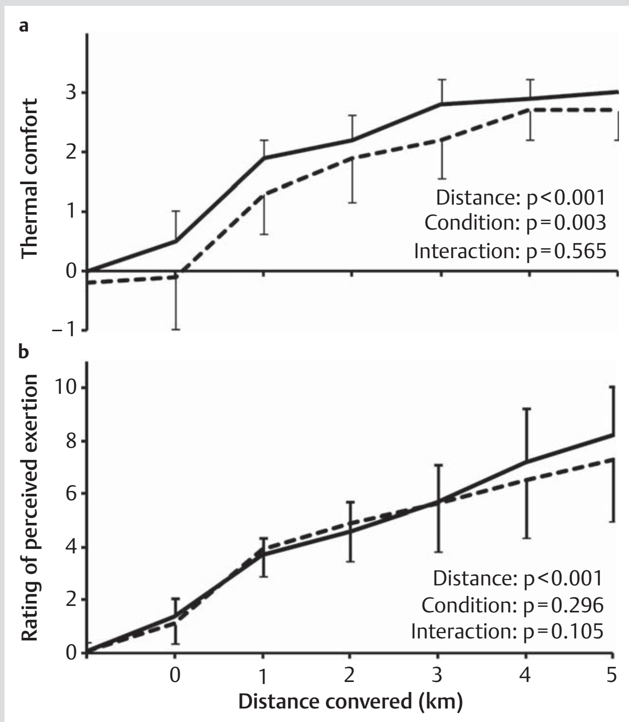

Fig. 4 Thermal comfort and rating of perceived exertion scores in the control (solid line) and the cooling vest condition (dashed line) during the 5-km time trial. **a** Thermal comfort scores increased significantly in both conditions ($p<0.001$), however the overall score was lower in the cooling vest compared to the control condition ($p=0.003$). **b** The rating of perceived exertion increased significantly during the 5-km time trial ($p<0.001$), with a comparable response across conditions. The error bars represent the SD.

tings are relatively uncommon, all studies that were performed at these high ambient temperatures found a positive effect of the cooling vest on running performance. In fact, a recent precooling study demonstrated that cycling performance was enhanced in environmental temperatures of 30 °C, but not at 25 °C [3, 14, 17]. These results suggest that a cooling vest is predominantly effective at high ambient temperatures, but may improve thermal comfort while exercising at lower ambient temperatures.

The strengths of the current study are the randomized crossover design and novel approach to using a cooling vest during exercise. Moreover, we measured all important parameters that relate to performance and thermoregulation, which provided us with detailed insight into the physiological responses during the time trial. However, some limitations should be taken into account. First, the circadian rhythm of the T_c could influence thermoregulatory responses during exercise [34]. Nevertheless, we successfully anticipated that by scheduling the 5-km time trials at the same time of the day resulting in a comparable baseline T_c ($p=0.40$) between the control (37.6 ± 0.3 °C) and cooling vest condition (37.5 ± 0.2 °C). Secondly, an inherent problem with (pre)cooling studies is the inability to blind the participants for the intervention, which could bias their performance. To remove any potential bias of our study design, we instructed all masters athletes that our primary goal was to test if the cooling capacity of the vest overrules the additional weight of wearing the vest during the 5-km time trial. Accordingly, the cooling vest could either have a positive (cooling) or negative (more weight) effect on the 5-km time trial performance. Finally, the cooling power (watts) of the vest is currently unknown, which limits the direct comparison with other cooling techniques.

The results of this study indicate that wearing a cooling vest during exercise is not effective in improving running performance in male competitive runners under temperate ambient conditions. Furthermore, wearing a cooling vest does not affect T_c during exercise. In contrast, the cooling vest did result in a lower HR, lower T_{sk} and improved thermal comfort in our master athletes. Furthermore, the additional weight of the cooling vest did not negatively impact on finish or split times. These findings suggest that although it does not enhance performance, wearing a cooling vest may be comfortable during practice. Future research should determine the optimal cooling capacity vs. weight of a vest that is worn during exercise. Combining our findings with data from previous studies suggest that a lightweight fabric with long-lasting and (ultra) low temperatures might be the optimal cooling strategy for competitive athletes.

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