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Postexercise Cooling Rates in 2 Cooling Jackets

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Context: Cooling jackets are a common method for removing stored heat accumulated during exercise. To date, the efficiency and practicality of different types of cooling jackets have received minimal investigation.

Objective: To examine whether a cooling jacket containing a phase-change material (PC17) results in more rapid postexercise cooling than a gel cooling jacket and a no-jacket (control) condition.

Design: Randomized, counterbalanced design with 3 experimental conditions.

Setting: Participants exercised at 75% $\dot{V}O_2max$ workload in a hot climate chamber (temperature = 35.0 ± 1.4°C, relative humidity = 52 ± 4%) for 30 minutes, followed by postexercise cooling for 30 minutes in cool laboratory conditions (ambient temperature = 24.9 ± 1.8°C, relative humidity = 39% ± 10%).

Patients or Other Participants: Twelve physically active men (age = 21.3 ± 1.1 years, height = 182.7 ± 7.1 cm, body mass = 76.2 ± 9.5 kg, sum of 6 skinfolds = 50.5 ± 6.9 mm, body surface area = 1.98 ± 0.14 m^2, $\dot{V}O_2max$ = 49.0 ± 7.0 mL·kg^{-1}·min^{-1}) participated.

Intervention(s): Three experimental conditions, consisting of a PC17 jacket, a gel jacket, and no jacket.

Main Outcome Measure(s): Core temperature (T_C), mean skin temperature (T_{Sk}), and T_C cooling rate (°C/min).

Results: Mean peak T_C postexercise was 38.49 ± 0.42°C, 38.57 ± 0.41°C, and 38.55 ± 0.40°C for the PC17 jacket, gel jacket, and control conditions, respectively. No differences were observed in peak T_C cooling rates among the PC17 jacket (0.038 ± 0.007°C/min), gel jacket (0.040 ± 0.009°C/min), and control (0.034 ± 0.010°C/min, $P > .05$) conditions. Between trials, no differences were calculated for mean T_{Sk} cooling.

Conclusions: Similar cooling rates for all 3 conditions indicate that there is no benefit associated with wearing the PC17 or gel jacket.

Key Words: PC17, hyperthermia, core temperature, skin temperature

Key Points

- Postexercise core cooling rates were similar for participants wearing a PC17 jacket, a gel jacket, or no jacket.
- Postexercise skin temperature cooling rates were also similar for participants wearing a PC jacket, a gel jacket, or no jacket.

Exercise performed in hot or humid conditions can result in hyperthermia, which in turn can impair exercise performance,[1] but more importantly, it can result in exertional heat illness.[2,3] To reduce core temperature (T_C), various cooling methods have been assessed,[4–17] including iced gastric and peritoneal lavage, pharmacologic-induced cooling, ice-pack application, evaporative cooling, and water immersion. Many of these methods provide efficient cooling rates, which are proposed[18] to be in excess of 0.2°C/min. Immediate cold-water immersion is the generally accepted "gold standard" technique for rapidly reducing T_C when exertional heat stroke is suspected (ie, core temperature ≥ 40°C).[16,17,19] When hyperthermia is mild (ie, core temperature slightly higher than 38°C),[20] other cooling methods may reduce the risk of exertional heat illness and provide relief to the athlete, allowing for a more rapid return to normothermia. Sensations of coolness associated with reductions in skin temperature may also offer some performance benefits to the athlete.[21] In these situations, the method chosen should be based primarily on effectiveness in reducing T_C, as well as on convenience and practicality.

Cooling jackets are a popular method for addressing mild hyperthermia, offering convenience and practicality, particularly in field sport situations in which water, equipment, or power sources may not be available for cold-water immersion or convection cooling. To date, only 2 studies[21,22] have assessed the effects of wearing cooling jackets after an exercise bout performed in hot conditions. Although greater reductions in T_C associated with wearing cooling jackets compared with a control condition were noted in both studies, only Webster et al[21] reported significant differences.

In addition to the benefits associated with cooling the body after exercise is performed in hot conditions, cooling the body *before* exercise in the heat has been reported[23–27] to improve subsequent exercise performance via precooling to increase heat storage capacity. This precooling, in turn, can delay the negative effects of hyperthermia, such as premature fatigue, which can result from increased carbohydrate metabolism and decreased oxygen delivery to the working muscles.[28] To date, improved exercise performance has been reported with the wearing of cooling jackets, either during the warm-up period[21,22] or during actual exercise performance.[24] Of note, a cooling jacket can also be used as a precooling agent between exercise bouts, for example, during a half-time break or rest or during interchange periods in many team sport games (eg, football, field hockey, basketball). Precooling can then result in enhanced cooling rates and improved subsequent exercise performance in the heat.[21,23,25–28] Research on the effectiveness of cooling jackets in reducing T_C after an initial exercise bout in the heat has been both limited and equivocal, so further investigation is warranted.

Of relevance, no authors have studied the effects of a conventional gel jacket on T_C cooling rates after a bout of exercise in the heat. Further, a cooling jacket has recently been designed that contains a new product called PC17, which appears as a crystalline substance and has phase-change properties. The cooling rate of PC17 has yet to be determined. Therefore, our purpose was to compare T_C cooling rates associated with the new PC17 jacket with those associated with a conventional gel cooling jacket and a no-jacket (control) condition after a 30-minute bout of exercise performed in hot environmental conditions.

METHODS

Participants

Twelve physically active men (age = 21.3 ± 1.1 years, height = 182.7 ± 7.1 cm, body mass = 76.2 ± 9.5 kg, sum of 6 skinfolds = 50.5 ± 6.9 mm, body surface area = 1.98 ± 0.14 m^2, maximal oxygen consumption [$\dot{V}O_2max$] = 49.0 ± 7.0 $mL \cdot kg^{-1} \cdot min^{-1}$) who were involved in approximately 8 hours of training and competition per week volunteered for the study. Because testing was conducted during the winter months, participants were not heat acclimatized. Before testing began, ethical approval was granted by the Human Research Ethics Committee of the University of Western Australia, and all participants provided written informed consent.

Research Design

We used a randomized, counterbalanced design in order to assess the effect of 2 cooling vests and a control condition on T_C cooling rates. Participants attended 4 testing sessions, the first being a familiarization session in which the procedures were outlined and demographic measures obtained. Three experimental trials were then performed approximately 1 week apart and at the same time of day to control for circadian variability. All participants exercised for 30 minutes in hot environmental conditions (ambient temperature = 35.0 ± 1.4°C, relative humidity [RH] = 52% ± 4%), followed by a 30-minute postexercise cooling period. This cooling period is similar to that used in Australian Rules football when a player sits on the interchange bench for a quarter; it is also similar to the half-time break when ambient conditions are hot. Descriptive variables measured during the exercise protocol included sweat loss, heart rate (HR), and the Borg rating of perceived exertion (RPE).[29] During the cooling period participants were randomly assigned (in a counterbalanced manner to avoid any order effects) to 1 of 3 experimental conditions. Experimental conditions (ie, independent variables) included the wearing of a cooling jacket containing either PC17 or gel and a control (no-jacket) condition. During the 30-minute cooling period, each participant sat quietly in an air-conditioned laboratory (ambient temperature = 24.9 ± 1.8°C, RH = 39% ± 10%). Dependent variables included T_C (measured via ingestible capsule; see "Thermoregulatory Responses" section) and mean skin temperature (T_{Sk}). These variables were measured at regular intervals during both the exercise and cooling periods.

Instruments

Cooling Jackets. Of the 3 experimental trials, 2 required participants to wear cooling jackets. On 1 occasion, participants wore a Heat Cooling Vest (Arctic Heat Products Pty Ltd, Burleigh Heads, Queensland, Australia), which is manufactured from Microfibre, Sportwool (Australian Wool Innovation, Sydney, New South Wales, Australia) and has 4 anterior and posterior pockets containing crystals. In accordance with the manufacturer's instructions, the cooling jacket was first placed in an ice-water slurry (icy water between 2°C and 5°C) for 30 minutes to activate the crystals to form a gel. The second cooling jacket was vest shaped and constructed from neoprene material. It had 4 anterior and 4 posterior pockets. Sealed packets (140 mm × 140 mm, 120 g each) of PC17 (PCP Australia, West Perth, Australia) were kept in a refrigerator (4°C) for the duration of the testing period and were placed into the pockets of the jacket at the start of the cooling period. A white, crystalline, solid substance, PC17 has the potential to transfer 3.5 W of heat/cm^2 from the body (based on the manufacturer's details). The melting point of PC17 is 17°C. As the pack melts, the transfer of heat reduces to 0.5 W/cm^2; shaking the packet increases the rate of heat transfer. Furthermore, a single pack transfers 50 to 350 W of heat. Each jacket was worn by the participant over exercising attire and was fitted using hook-and-loop straps. Neither jacket used in our study had a hood, and, therefore, the participants' heads remained uncovered during all trials. The control condition involved no jacket being worn.

Thermoregulatory Responses. To assess thermoregulatory responses during the exercise and cooling periods, we measured T_C and T_{Sk} using the VitalSense system (Mini Mitter Co, Inc, Bend, OR). Core temperature was determined using an ingestible capsule (Jonah ingestible capsule; Mini Mitter Co, Inc), which was activated and swallowed 8 hours before the testing session. As a result of budget limitations, skin temperatures were only obtained from a subset of participants (n = 6) and were measured using dermal patches (Mini Mitter Co, Inc) that were positioned on the sternum (below the sternal notch), medial forearm, and mid-posterior calf. Both T_C and T_{Sk} values were transmitted from the capsule and dermal patches, respectively, to a monitor (VitalSense integrated physiological monitor; Mini Mitter Co, Inc). Mean T_{Sk} was calculated using the method described by Burton[30] in 1934: mean skin temperature = (0.5 × sternum temperature) + (0.14 × forearm temperature) + (0.36 × calf temperature).

Sweat Loss. Nude body mass was measured using a digital platform scale (model ED3300; Sauter Multi-Range, Ebingen, West Germany) accurate to ±10 g. Before exercising, participants entered a private room and disrobed (taking off all articles of clothing and accessories except for the 3 dermal patches), and body mass measurement was read from the display unit. Postexercise nude body mass was obtained in the same fashion after participants had towel-dried themselves. Nude mass was obtained in order to minimize errors associated with sweat trapped in clothing and measurement devices. Sweat loss was calculated by the difference between pre-exercise and postexercise body mass while accounting for the ingestion of 300 mL of water.

Environmental Conditions. Ambient temperature and RH were measured during the exercise and cooling periods using a digital temperature and humidity meter (model 971; Fluke Corporation, Everett, WA). This device has a temperature range of −20°C to 60°C, with an accuracy of ±0.5°C for temperatures between 0°C and 45°C; the humidity range is 5% to 95%, with an accuracy of ±2.5% for conditions between 10% and 90%. Values provided by this device consistently matched temperature and humidity values that were recorded independently in the climate chamber.

Experimental Procedures

Familiarization Session. Participants initially completed a familiarization session in which we instructed them in the procedures of the study and took anthropometric measurements. Anthropometric assessment included height (cm), body mass (kg), sum of 6 skinfolds (mm, subscapular, chest, midaxillary, suprailiac, abdominal, and thigh using Harpenden skinfold calipers [Baty Intl, West Sussex, United Kingdom]), and body surface area (m^2, Dubois nomogram[20]). In addition, participants completed a $\dot{V}O_2max$ test to ensure that they exercised at similar relative intensities during the experimental trials. The $\dot{V}O_2max$ test was performed on a cycle ergometer with a starting intensity of 100 W, which was increased by 50 W every 3 minutes until volitional exhaustion was achieved. After a 15-minute break, participants then cycled for 15 minutes at 75% of their $\dot{V}O_2max$ workload in the climate chamber, which was set at approximately 35°C and 50% RH to resemble the conditions used during the experimental trials.

Participants were required to abstain from alcohol and vigorous activity for 24 hours before testing and from caffeine for 3 hours before testing. In addition, they were required to wear the same clothing during each testing session and to replicate food and fluid intake before and during each session.

Exercise Protocol. Baseline measurements were made before participants began the experimental trials. All volunteers underwent the same protocol, with the exception of those in the skin temperature subset group, who had the dermal patches attached to their bodies as described earlier. Nude body mass was recorded and participants were fitted with HR monitors (model F1 heart rate monitor; Polar Electro, Kempele, Finland). Baseline measurements for T_C, T_{Sk}, and HR were then recorded.

Once preliminary procedures were completed, participants performed a 30-minute continuous bout of exercise in a climate chamber set at 35.0 ± 1.4°C (dry bulb temperature) and 52% ± 4% RH. The mode of exercise was cycling on a bicycle ergometer (model Ergomedic 818; Monark Exercise AB, Vansbro, Sweden) at 75% $\dot{V}O_2max$ workload, which corresponded to a mean power output of 199 ± 39 W. During the exercise protocol, participants consumed 100 mL of water every 10 minutes to standardize fluid intake. Both T_C and HR were measured every 5 minutes, whereas T_{Sk} was measured every 10 minutes. Each participant's RPE was recorded at the 15-minute and 30-minute time points of the exercise trial.

Transition and Cooling Period. After the exercise session, participants left the climate chamber and nude body mass was recorded. Within 5 minutes of completing the exercise protocol, one of the cooling methods was undertaken for 30 minutes. During this time, the volunteer sat in an air-conditioned laboratory (ambient temperature = 24.9 ± 1.8°C, RH = 39% ± 10%) and received 100 mL of water every 10 minutes. The T_C was measured every 5 minutes and the T_{Sk}, every 10 minutes. At the end of the cooling period, participants were given additional fluids and were free to leave the laboratory.

Statistical Analysis

We used a repeated-measures, 1-way analysis of variance to assess HR, T_C, mean T_{Sk}, RPE, sweat loss, and environmental conditions. Where appropriate, Bonferroni post hoc comparisons were also used. Statistical significance was set at $P \leq .05$ for all analyses, and data were analyzed using SPSS (version 13.0 for Windows; SPSS Inc, Chicago, IL). Cooling rates were calculated by the change in T_C/30 min, where the change in T_C was the difference between T_C recorded at the 30-minute mark of the recovery period and T_C recorded at the end of the 30-minute exercise protocol. Peak T_C values were also determined. These occurred either at the end of the 30-minute exercise protocol or at 5 minutes postexercise during the recovery period. Changes in T_C and cooling rates were also calculated using this value.

RESULTS

No differences were seen between environmental conditions during the exercise period (ambient temperature: $F_{2,22} = 0.99$, $P = .39$; RH: $F_{2,22} = 0.05$, $P = .95$) or during the postexercise cooling period (ambient temperature: $F_{2,22} = 0.44$, $P = .65$; RH: $F_{2,22} = 0.04$, $P = .96$) for the 3 trials. In addition, participants' RPE values at the 15-minute and 30-minute marks of the exercise protocol (approximately 15 ± 2 and 17 ± 2: $F_{2,22} = 0.76$, $P = .48$; $F_{2,22} = 1.0$, $P = .38$, respectively) and sweat loss (approximately 0.55 ± 0.16 kg: $F_{2,22} = 2.09$, $P = .15$) were also not different among trials. Similarly, HR values were not different during exercise among trials, increasing from resting levels (75 ± 7 beats/min) to 179 ± 12 beats/min at the end of the exercise protocol ($F_{2,22} = 0.01$, $P = .99$).

Core temperature increased, on average, by approximately 1.3°C over the exercise period (Table 1). No differences for T_C were observed at baseline (0 minutes: $F_{2,22} = 0.21$, $P = .82$) or at the end of the exercise (30 minutes: $F_{2,22} = 0.10$, $P = .90$) among the 3 trials (Table 1). Peak T_C values, recorded either after 30 minutes of exercise (n = 8, n = 8, and n = 9 for PC17, gel, and no-jacket conditions, respectively) or 5 minutes into recovery (n = 4, n = 4, and n = 3 for PC17, gel, and no-jacket conditions, respectively), were also analyzed, but again, no differences existed among trials ($F_{2,22} = 0.24$, $P = .79$; Table 1). In addition, no differences were noted among trials for the change in T_C from baseline to the end of the 30-minute exercise protocol ($F_{2,22} = 0.02$, $P = .98$) or from baseline to peak T_C values ($F_{2,22} = 0.02$, $P = .98$; Table 1). Collectively, these results demonstrated that the partici-

Table 1. Core Temperature Responses (°C) During Exercise and Postexercise Cooling (n = 12) (Mean ± SD)[a]

	Exercise Period					Postexercise Cooling Period		
	Baseline	30 Minutes	ΔT_C 1[b]	Peak T_C	ΔT_C 2[c]	30 Minutes	Cooling Rate 1 (°C/min)[d]	Cooling Rate 2 (°C/min)[e]
Experimental condition								
PC17 jacket	37.14 ± 0.32	38.44 ± 0.42	1.30 ± 0.43	38.49 ± 0.42	1.35 ± 0.44	37.42 ± 0.29	0.034 ± 0.008	0.038 ± 0.007
Gel jacket	37.20 ± 0.20	38.49 ± 0.43	1.29 ± 0.44	38.57 ± 0.41	1.37 ± 0.42	37.45 ± 0.32	0.035 ± 0.012	0.040 ± 0.009
No jacket	37.18 ± 0.43	38.50 ± 0.40	1.32 ± 0.20	38.55 ± 0.40	1.37 ± 0.24	37.56 ± 0.28	0.031 ± 0.012	0.034 ± 0.010

Abbreviation: T_c, core temperature.
[a] There were no differences among conditions ($P < .05$).
[b] ΔT_C 1 indicates change from baseline T_C to 30 minutes.
[c] ΔT_C 2 indicates change from baseline T_C to peak T_C (30 minutes of exercise or 5 minutes of recovery).
[d] Cooling rate 1 indicates mean change in T_C from 30 minutes of exercise to 30 minutes of recovery/30 minutes.
[e] Cooling rate 2 indicates mean change in T_C from peak T_C (30 minutes of exercise or 5 minutes of recovery) to 30 minutes of recovery/30 minutes.

pants responded similarly in each experimental trial and were not different in their physiologic states as they began the postexercise recovery period.

In the recovery cooling period, no differences were found among trials for T_C at the end of the recovery period (30 minutes: $F_{2,22} = 1.51$, $P = .25$) or for changes in T_C from the end of the exercise period (30 minutes) to the end of the recovery period (30 minutes: $F_{2,22} = 0.55$, $P = .58$) or from when peak T_C occurred to the end of the recovery period (30 minutes: $F_{2,22} = 1.44$, $P = .26$; Table 1). Cooling rates (end of exercise to end of 30 minutes of recovery and peak value to end of 30 minutes of recovery) were also not different among conditions ($F_{2,22} = 0.55$, $P = .59$, and $F_{2,22} = 2.64$, $P = .09$, respectively; Table 1).

Mean T_{Sk} values increased similarly (by approximately 6°C to 7°C) from baseline to the end of the 30-minute exercise period in all 3 trials (Table 2). After the postexercise cooling period, mean T_{Sk} had decreased by 4°C to 5°C (Table 2). No differences were found among trials for mean T_{Sk} measured at baseline ($F_{2,10} = 0.98$, $P = .41$) or at the end of 30 minutes of exercise ($F_{2,10} = 1.86$, $P = .21$) or for changes in mean T_{Sk} measured from baseline to the end of 30 minutes of exercise ($F_{2,10} = 1.12$, $P = .36$). Similarly, no differences were revealed among trials after 30 minutes of recovery ($F_{2,10} = 2.25$, $P = .16$) or for changes in mean T_{Sk} measured at the end of 30 minutes of exercise to the end of the 30-minute recovery period ($F_{2,10} = 0.76$, $P = .49$; Table 2).

DISCUSSION

Exercise in hot or humid conditions results in an elevated T_C,[2] which can cause premature fatigue and, in some circumstances, exertional heat illness.[6] Precooling the body before exercise or between exercise bouts performed in the heat has been reported[21,23,26,27] to improve subsequent exercise performance, whereas cooling performed immediately postexercise can reduce the risk or consequences of exertional heat illness.[21] When the athlete is not at risk of exertional heat stroke but may be suffering from mild hyperthermia, cooling jackets may be appropriate for reducing T_C because of their convenience and practicality compared with other cooling methods. We conducted this study to determine whether a cooling jacket containing a new phase-change material, PC17, was a superior cooling agent with respect to cooling rates, convenience, and practicality, compared with a conventional gel jacket and a control (no-jacket) condition.

With respect to lowering T_C, only small and nonsignificant differences among the 3 conditions were noted. Although the finding was not statistically significant, the gel jacket produced a slightly higher cooling rate than the PC17 jacket (0.040 ± 0.009°C/min versus 0.038 ± 0.007°C/min; Table 1). This result may be attributed to the preapplication temperature of the jacket: the gel jacket was soaked in ice water before wearing, whereas the frozen PC17 packs were placed into the pockets of a dry jacket. Therefore, the gel jacket may have had a lower preapplication temperature. This finding supports the Fournier Law, which describes conductive heat transfer and states "per unit area the transfer in a given direction is proportional to the temperature gradient."[12] Later findings by Kennet et al[12] did not support this law, with the researchers suggesting that agents undergoing phase change were not accounted for within this law. The authors[12] proposed that phase-change products, such as PC17, can absorb heat and maintain a consistent temperature throughout their period of use. The lack of support in our study for the conclusion of Kennet et al[12] may be attributed to the fact that PC17 has a melting point of 17°C and remains cooler at higher

Table 2. Skin Temperature (°C) During Exercise and Postexercise Cooling (n = 6) (Mean ± SD)[a]

	Exercise Period			Postexercise Cooling Period	
	Baseline	30 Minutes	ΔT_{Sk} 1[b]	30 Minutes	ΔT_{Sk} 2[c]
Experimental condition					
PC17 jacket	30.82 ± 1.35	37.15 ± 0.39	6.33 ± 1.55	32.86 ± 0.39	4.29 ± 0.55
Gel jacket	29.87 ± 2.23	36.91 ± 0.23	7.04 ± 2.22	32.48 ± 0.57	4.43 ± 0.58
No jacket	31.00 ± 1.66	36.75 ± 0.53	5.75 ± 0.53	32.03 ± 0.80	4.72 ± 0.55

Abbreviation: T_{Sk}, skin temperature.
[a] No differences were noted among conditions ($P < .05$).
[b] ΔT_{Sk} 1 indicates change in T_{Sk} from baseline to 30 minutes.
[c] ΔT_{Sk} 2 indicates change in T_{Sk} from 30 minutes of exercise to 30 minutes of recovery.

temperatures for longer than other cooling agents. Therefore, the fixed period of postexercise cooling used in this current study (30 minutes) may not have been long enough for the PC17 to show any advantage in cooling rates, whereas a longer postexercise cooling time period may have produced results that were more consistent with the findings of Kennet et al.[12] Furthermore, according to the manufacturer, as the PC17 packs melt, shaking the pack increases heat transferring efficiency. We did not shake the packs in our study, but subjectively, the PC17 was not noticeably depleted or different in appearance after the 30-minute cooling period. This is a limitation to our study, because shaking the pack during the cooling period might have resulted in a difference in the cooling rate associated with this product. Additionally, assessing T_C over a shorter recovery period might have resulted in different mean cooling rates among conditions, whereas higher postexercise T_C values might have been needed to induce significantly higher cooling rates.

The efficiency of cooling jackets in reducing T_C after an exercise bout is an area of research with limited available data. To our knowledge, the only comparable studies using similar research designs and cooling techniques were conducted by Lopez et al[22] and Webster et al,[21] both of whom tested the postexercise cooling efficiency of an ice jacket compared with a control condition. Webster et al[21] reported that ice jackets designed for sporting situations resulted in decreases in T_C, compared with a control condition, after 20 minutes of recovery after the completion of exercise performed in hot conditions (ambient temperature = 37°C, RH = 50%). Actual cooling rates were not reported. Differences in their results compared with ours may be due to the use of ice rather than gel or PC17, different methods for T_C measurement (rectal thermister versus ingestible capsule), and the possibility that their postexercise T_C was higher (actual data not reported) than those in the current study. Conversely, Lopez et al[22] noted no differences in cooling with the ice jacket compared with a control condition, although the ice-jacket condition produced slightly higher cooling rates (0.0298°C/min versus 0.0280°C/min) and returned T_C from 38.7 ± 0.3°C to baseline levels 22.6% faster than did the control condition.

Comparing cooling rates between the above-mentioned and present studies indicates that the PC17 (0.038°C/min) and the gel jacket (0.040°C/min) were more efficient in decreasing T_C per minute than was the HeatShield cooling vest (ClimaTech Safety, Inc, White Stone, VA) used by Lopez et al[22] (0.0298°C/min).

When compared with other common cooling methods used to reduce T_C, such as ice-pack application, water immersion, and evaporative cooling, it appears that the PC17 and gel jackets only provided cooling rates superior to the application of ice packs[7] and, in some instances, evaporative cooling.[7] A cooling rate of 0.028°C/min was recorded when 6 ice packs were strategically placed on the body, with this rate increasing to 0.034°C/min when the body was completely covered with ice packs.[7] Further, evaporative cooling (ie, cooling resulting from the movement of air on the body), which was applied after water had been splashed intermittently on the body by hand, resulted in a cooling rate of 0.034°C/min.[7] When both methods were performed simultaneously, the result was a slightly greater cooling rate of 0.036°C/min. Previous researchers have demonstrated that cooling methods such as water immersion and other forms of evaporative cooling can produce even more rapid cooling rates. For example, water immersion, as used by Proulx et al,[31] resulted in the fastest cooling rate yet reported (0.35°C/min) when applied to a T_C of 40°C. In addition, a cooling rate of 0.31°C/min was cited with evaporative cooling, which involved the combination and continual spraying of cool (15°C) water and warm air (45°C) over the entire body in order to maintain a constant skin temperature of 32°C to 33°C.[14] This process reduced T_C from 39.5°C to 37.5°C within 4.3 to 7.5 minutes.[14] These significantly higher cooling rates, compared with those of the PC17 and gel jacket, are to be expected, as these methods involved whole-body cooling techniques, whereas the jackets used in the current study only provided direct conductive cooling to the torso region.

With reference to mean T_{Sk}, no differences were found among conditions. Lopez et al[22] also found no differences between their cooling jacket and the no-jacket conditions. They suggested[22] that reactive hyperemia, due to greater cutaneous vasodilation, resulted in the warming of the vest layer closest to the skin, increasing skin temperature and consequently retarding the jacket's cooling efficiency. This process may have also been relevant in our study. Conversely, although no visual signs of shivering were present, participants may have experienced minor vasoconstriction of the peripheral vessels, thereby reducing the decline in T_{Sk}. Of interest, cooling rates for T_C were slightly higher in the jacket conditions, but not for mean T_{Sk}. This may be explained in part by the slightly lower mean T_{Sk} recorded after 30 minutes of exercise in the no-jacket condition. Further, the jackets may have aided heat transfer from the core to the periphery, thereby causing slightly warmer skin temperatures in these conditions during the postexercise recovery.

Although we found no differences in cooling rates between the PC17 and gel jackets, the practicality of the PC17 jacket should be considered. The PC17 has the ability to stay colder at higher temperatures than do other agents, primarily as a result of the higher melting point (17°C) of PC17, and as a phase-change material, PC17 can maintain a constant temperature throughout its period of use. A single 200-g PC17 pack can remove 50 to 350 W of heat from the body, depending on conditions such as ambient temperature, body temperature, and material density placed between the product and the skin. With regard to field settings, PC17 is easy to transport in its active state, as it can maintain its temperature (after refrigeration) while carried in a portable cooler bag. Additionally, PC17 does not require any real effort to preactivate, unlike the gel jacket, which must be immersed in ice water for at least 30 minutes. Therefore, in comparison with other cooling methods used for precooling or to treat mild hyperthermia, the PC17 requires little additional effort and has no negative consequences for the individual. For example, techniques such as water immersion, when used as a precooling agent or to treat mild hyperthermia, require much organization and pose issues such as availability of equipment and water. Evaporative cooling can also be somewhat impractical in the field because the necessary equipment and a power source may not be available; in addition, environmental conditions may inhibit the effectiveness of the treatment.

CONCLUSIONS

We found no differences in cooling rates among the 2 jacket conditions and the control condition. Further research is required to ascertain the cooling rate of PC17 in a hot and humid environment; further research is also required for situations in which postexercise T_C is higher than that achieved in the current study. In addition, the effectiveness of using PC17 during exercise and its potential to enhance subsequent performance as a precooling agent during hot and humid conditions need to be investigated.

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REFERENCES

1. Galloway SDR, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc*. 1997;29(9):1240–1249.
2. Casa DJ. Exercise in the heat, I: fundamentals of thermal physiology, performance implications, and dehydration. *J Athl Train*. 1999;34(3):246–252.
3. Davies CTM, Brotherhood JR, Zeidifard E. Temperature regulation during severe exercise with some observations on effects of skin wetting. *J Appl Physiol*. 1976;41(5 pt 1):772–776.
4. Smith JE. Cooling methods used in the treatment of exertional heat illness. *Br J Sports Med*. 2005;39(8):503–507.
5. Casa DJ. Exercise in the heat, II: critical concepts in rehydration, exertional heat illnesses, and maximizing athletic performance. *J Athl Train*. 1999;34(3):253–262.
6. Hadad E, Rav-Acha M, Heled Y, Epstein Y, Moran DS. Heat stroke: a review of cooling methods. *Sports Med*. 2004;34(8):501–511.
7. Kielblock AJ, Van Rensburg JP, Franz RM. Body cooling as a method for reducing hyperthermia: an evaluation of techniques. *S Afr Med J*. 1986;69(6):378–380.
8. Horowitz BZ. The golden hour in heat stroke: use of iced peritoneal lavage. *Am J Emerg Med*. 1989;7(8):616–619.
9. Bouchama A, Cafege A, Devol EB, Labdi O, el-Assil K, Seraj M. Ineffectiveness of dantrolene sodium in the treatment of heatstroke. *Crit Care Med*. 1991;19(2):176–180.
10. Channa AB, Seraj MA, Saddique AA, Kadiwal GH, Shaikh MH, Samarkandi AH. Is dantrolene effective in heat stroke patients? *Crit Care Med*. 1990;18(3):290–292.
11. Enwemeka CS, Allen C, Avila P, Bina J, Konrade J, Munns S. Soft tissue thermodynamics before, during, and after cold pack therapy. *Med Sci Sports Exerc*. 2002;34(1):45–50.
12. Kennet J, Hardaker N, Hobbs S, Selfe J. Cooling efficiency of 4 common cryotherapeutic agents. *J Athl Train*. 2007;42(3):343–348.
13. Khogali M, Weiner JS. Heat stroke: report on 18 cases. *Lancet*. 1980;2(8189):276–278.
14. Weiner JS, Khogali M. A physiological body-cooling unit for treatment of heat stroke. *Lancet*. 1980;1(8167):507–509.
15. Wyndham CH, Strydom NB, Cooke HM, et al. Methods of cooling subjects with hyperpyrexia. *J Appl Physiol*. 1959;14(5):771–776.
16. Armstrong LE, Crago AE, Adams R, Roberts WO, Maresh CM. Whole-body cooling of hyperthermic runners: comparison of two field therapies. *Am J Emerg Med*. 1996;14(4):355–358.
17. Clapp AJ, Bishop PA, Muir I, Walker JL. Rapid cooling techniques in joggers experiencing heat strain. *J Sci Med Sport*. 2001;4(2):160–167.
18. Tek D, Olshaker JS. Heat illness. *Emerg Med Clin North Am*. 1992;10(2):299–310.
19. Casa DJ, McDermott BP, Lee EC, Yeargin SW, Armstrong LE, Maresh CM. Cold water immersion: the gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141–149.
20. McArdle W, Katch F, Katch V. *Exercise Physiology. Energy, Nutrition, and Human Performance*. Baltimore, MD: Lippincott Williams & Wilkins; 2001:191.
21. Webster J, Holland EJ, Sleivert G, Laing RM, Niven BE. A light-weight cooling vest enhances performance of athletes in the heat. *Ergonomics*. 2005;48(7):821–837.
22. Lopez RM, Cleary MA, Jones LC, Zuri RE. Thermoregulatory influence of a cooling vest on hyperthermic athletes. *J Athl Train*. 2008;43(1):55–61.
23. Arngrimsson SA, Petitt DS, Stueck MG, Jorgensen DK, Cureton KJ. Cooling vest worn during active warm-up improves 5-km run performance in the heat. *J Appl Physiol*. 2004;96(5):1867–1874.
24. Hasegawa H, Takatori T, Komura T, Yamasaki M. Wearing a cooling jacket during exercise reduces thermal strain and improves endurance exercise performance in a warm environment. *J Strength Cond Res*. 2005;19(1):122–128.
25. Lee DT, Haymes EM. Exercise duration and thermoregulatory responses after whole body precooling. *J Appl Physiol*. 1995;79(6):1971–1976.
26. Marsh D, Sleivert G. Effect of precooling on high intensity cycling performance. *Br J Sports Med*. 1999;33(6):393–397.
27. Yeargin SW, Casa DJ, McClung JM, et al. Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength Cond Res*. 2006;20(2):383–389.
28. Bolster DR, Trappe SW, Short KR, et al. Effects of precooling on thermoregulation during subsequent exercise. *Med Sci Sports Exerc*. 1999;31(2):251–257.
29. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. 1970;2(3):92–98.
30. Burton AC. A new technique for the measurement of average skin temperature over surfaces of the body and the changes of skin temperature during exercise. *J Nutr*. 1934;7(5):481–496.
31. Proulx CI, Ducharme MB, Kenny GP. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol*. 2003;94(4):1317–1323.

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