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Human Kinetics
ORIGINAL INVESTIGATION

Improved 2000-m Rowing Performance in a Cool Environment With an External Heating Garment

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Purpose: Rowers can be in marshaling areas for up to 20 to 25 min before the start of a race, which likely negates any benefits of an active warm-up, especially in cold environments. It is unknown if using a heated jacket following a standardized rowing warm-up can improve 2000-m rowing performance. ***Methods:*** On 2 separate occasions, 10 trained male rowers completed a standardized rowing warm-up, followed by 25 min of passive rest before a 2000-m rowing time trial on a rowing ergometer. Throughout the passive rest, the participants wore either a standardized tracksuit top (CON) or an externally heated jacket (HEAT). The trials, presented in a randomized crossover fashion, were performed in a controlled environment (temperature 8°C, humidity 50%). Rowing time-trial performance, core body temperature, and mean skin temperature, along with perceptual variables, were measured. ***Results:*** During the 25-min period, core body temperature increased in HEAT and decreased in CON (Δ0.54°C [0.74°C] vs –0.93°C [1.14°C]; $P = .02$). Additionally, mean skin temperature (30.22°C [1.03°C] vs 28.86°C [1.07°C]) was higher in HEAT versus CON ($P < .01$). In line with the physiological data, the perceptual data confirmed that participants were more comfortable in HEAT versus CON, and subsequently, rowing performance was improved in HEAT compared with CON (433.1 [12.7] s vs 437.9 [14.4] s, $P < .01$). ***Conclusion:*** The data demonstrate that an upper-body external heating garment worn following a warm-up can improve rowing performance in a cool environment.

Keywords: clothing, passive heating, rowers, temperature

Rowing is a physiologically demanding sport, due to the recruitment of a large muscle mass and work rates near rowers' maximal physical capacity.[1,2] Rowers possess large body dimensions and produce among the largest values of any athlete in the specific parameters of physical fitness, involving those related to muscular and cardiorespiratory function,[3] such that warming up prior to a rowing race is an integral part of the preparation phase. Generally, after the warm-up period, rowers must be in the marshalling area ~10 to 15 minutes before the start of a race, and the transition phases between warm-up and the beginning of a race can be as long as 20 to 25 minutes. It appears that there is an increased risk of a reduction in core temperature (T_{core}), with longer transitions,[4] and such a reduction in this time has been found to attenuate the overall decline in the T_{core}, significantly improving performance times.[5,6] However, there is little scope to alter rowing competition schedules by a large margin. Therefore, methods are needed to support rowers in maintaining muscle activation and raised core and muscle temperature during such transition periods. A rise in muscle temperature results in various physiological benefits, including an increased speed of contraction and relaxation of muscle fibers, increased anaerobic metabolic capacity, and nerve conduction enhancements in both the peripheral and central nervous system.[7] Therefore, the transition time offers a period for experimental implementation of different strategies to counter the decline in T_{core} and, subsequently, improve performance.

Recent literature has combined an active warm-up with heated tracksuit pants in the marshalling period before a sprint cycling race, which improved core and muscle temperature maintenance, along with time-trial (TT) performance (~2%).[8] More specifically, the combination of an active swimming warm-up followed by the use of an upper-body passive heating device in the "call room" improved maintenance in the core and muscle temperature and overall swimming performance to a similar extent.[5,9] However, although those studies observed significant improvements in performance, few studies have determined the physiological outcomes of a passive warm-up during long duration exercise performance (≥5 min); this is partly due to the fact that there are detrimental physiological factors that negatively impact performance in such circumstances. Gregson et al[10] reported that following a passive warm-up, which increased the T_{core} to 38.0°C, significantly decreased the time to exhaustion to 70% of the maximum aerobic capacity. Similarly, the same authors also observed that warming up passively significantly decreases high-intensity intermittent exercise time to exhaustion at an ambient temperature (21.7°C).[11] This negative effect on performance is thought to be because of the impaired thermoregulatory mechanisms and/or a decrease in heat storage capacity, resulting in an accelerated accumulation of metabolites and/or an earlier attainment of a high core temperature.[10] However, at a lower ambient temperature (5°C), a significantly higher heat-storage capacity exists compared with standard ambient conditions (18–20°C).[12] This may delay the onset of a critical core temperature during long-duration rowing in cool conditions and seems to provide valid reasoning for a passive heating device to improve core and muscle temperature maintenance throughout the lengthy transition periods experienced during competitive rowing. The combination of an upper-body passive heating device worn throughout the transition period between the warm-up and race may elicit performance enhancing benefits.

Accordingly, the purpose of this study was to determine if the use of an externally heated jacket during the transition phase could improve 2000-m single scull rowing performance. It was hypothesized that the heated jacket would improve performance

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in a cool environment by attenuating the decline in body temperature.

Methods

Participants

A total of 10 trained male rowers participated in this study (age, 24.1 [2.89] y; stature, 1.85 [0.4] m; body mass, 77.61 [5.49] kg). The population was defined as a rower who regularly competes in key regional or national tournaments, and for the sample studied, the rowers had competed for 4 (2) years and trained 5 (1) times a week, for a total of 7 (3) hours. A sample size of 10 was calculated using a change in mean 2000-m rowing TT performance, a crossover design in a similar population, and the SD of nontapered performance times (±23.4 s). A statistical power of .8 and the smallest worthwhile improvement in performance of 1%[13] was used (version 18, Mini Tab; Minitab Ltd, Coventry, United Kingdom). None of the participants supplemented their diets with any putative ergogenic aid for 6 months before the start of the study. All participants were informed of the experimental procedures, potential benefits, value of the likely findings, and associated risks before providing informed consent to participate. The participants were asked to avoid the consumption of caffeine and alcohol and refrain from any vigorous exercise 24 hours before all testing. The participants were also asked to emulate their food consumption during the course of the study. Additionally, foot position and rowing drag on the rowing ergometer remained the same across all visits.

Experimental Design

This study used a within-participant, randomized, and counterbalanced experimental design. Each participant was required to visit the environmental chamber (TIS Services, Alton, Hampshire, United Kingdom) on 3 separate occasions, with each session ~7 days apart. The trials were performed at the same time of day (±1 h) to minimize circadian effects. Before the 2 experimental sessions, the participants were familiarized with the exercise protocol, and initial measurements were taken (age, stature, and body mass). The participants then entered the environmental chamber, with the temperature (8°C) and humidity (50%) controlled to reflect common morning conditions experienced at the start of the competitive United Kingdom outdoor rowing season (March). During each visit, the participants completed a 10-min standardized rowing warm-up,[14] followed by 25 minutes of passive rest, replicating the time between the completion of a warm-up and the beginning of a race. During the passive rest, the participants wore a pair of standardized tracksuit bottoms with a standardized tracksuit top (CON) or an externally heated jacket (HEAT; Powerlet rapidFIRe Proform Heated Jacket Liner, Warren, MI). Following the passive rest, the clothing was removed, and a 2000-m TT was performed on a rowing ergometer (Concept2, Nottingham, United Kingdom).

Procedure

The participants arrived at the environmental chamber after consuming a meal typically ~2 hours prior to testing. Upon arrival, following the baseline measurements of stature and body mass (Seca Ltd, Birmingham, United Kingdom), a calibrated aural thermistor (Grant Instruments, Cambridge, United Kingdom), was inserted into the participant's right auditory canal to estimate the T_{core}. The thermistor was securely taped into position and insulated with cotton wool[15] before a headband was fitted to maintain placement. Additionally, wired skin thermistors (Grant Instruments) were then attached to the forearm ($T_{Forearm}$), chest (T_{Chest}), and calf (T_{Calf}) for the calculation of mean skin temperature (T_{sk}; $T_{sk} = 0.5 \times T_{Chest} + 0.36 \times T_{Calf} + 0.14 \times T_{Forearm}$).[16] The skin thermistors were placed over the skin and secured in place using an adhesive spray and tape; both aural and skin thermistors were connected to a data logger (Squirrel SQ2020 Data Logger; Dorset, United Kingdom) that sampled data in 10-second epochs. A heart rate (HR) monitor was also fitted (Polar FT1; Polar Electro Oy, Kempele, Finland) prior to entering the chamber.

Once the participants entered the environmental chamber, they were seated for a 10-minute stabilization period; during this time, the participants wore a standardized tracksuit composed of a zipped-up tracksuit top and trouser bottoms, both consisting of a single layer of nylon material, with minimal insulation. Following the stabilization period, the baseline measurements were recorded, beginning with a capillary blood sample (20 μL) from the earlobe to measure blood lactate (BLa) using a calibrated, automated system (Biosen 5030; EKF Industrie, Elektronik GmbH, Barleben, Germany). Additionally, the T_{core}, T_{Chest}, T_{Calf}, $T_{Forearm}$, and HR were recorded, as well as thermal comfort (TC) and thermal sensation (TS), using visual analog scales.[17] The number range for both scales was consistent but anchors varied (TC: −3 = very uncomfortable, −2 = uncomfortable, −1 = just uncomfortable, 0 = neutral, 1 = just comfortable, 2 = comfortable, 3 = very comfortable; TS: −3 = cold, −2 = slightly cold, −1 = cool, 0 = neutral, 1 = warm, 2 = slightly hot, 3 = hot). The participants then completed a standardized 10-min rowing warm-up, using 18 to 20 strokes per minute.[14] Immediately after the warm-up, the participants were seated for 25 minutes, simulating the "marshalling period" between the warm-up and the beginning of a rowing race. The participants wore a long-sleeve T-shirt, standardized tracksuit trouser bottoms, and CON or HEAT; both jackets' insulations were similar when unheated. The heated jacket (Powerlet rapidFIRe Proform) was chosen because of the optimal coverage of the torso and arms with the heating elements in comparison to other varieties. The key upper-body muscle groups (lower deltoids, triceps brachii, pectoralis major, and the latissimus dorsi) used for rowing were covered by the heating elements that were powered (12 V, 10 A) enabling capacity of 105 W. The jacket's stretch panels allowed for optimal heat transfer, as the material is maintained close to the body, thus decreasing convection, while allowing movement. The maximum temperature of the heating elements was 50°C but the T_{sk} is known to be lower.[5] The long-sleeve T-shirt was worn under the jacket to eliminate the likelihood of burning, and ratings of TC and TS were made throughout the entire protocol. The participants were asked to ensure that the jacket felt "comfortable (≤2)" and "hot (≤3)." If the participant felt "uncomfortable (≥−2)," the heat stimulus was reduced. As the garment is used for subzero conditions, a maximum level of possible heating was never encroached upon. Over the duration of the 25-minute period, all temperature-related measurements were recorded every 5 minutes. Following the passive period, the tracksuits were removed, and the participants performed the 2000-m rowing TT, replicating the single scull event. The participants were instructed to complete the distance in the fastest possible time and were blinded to feedback. Performance was recorded as the time to completion (s), with HR measured throughout (every 30 s) and BLa measured immediately post.

Data Analysis

The data are presented as mean (SD) unless stated otherwise, and all data were analyzed using GraphPad Prism (version 7.04; GraphPad Software, San Diego, CA). Prior to the analyses, normality of data was assessed using the Kolmogorov–Smirnov test (SPSS version 26; IBM Corp, Armonk, NY). The parameters measured throughout the passive period were analyzed using a 2-way repeated-measures analysis of variance (condition [2], time [6]), with multiple comparisons corrected using the Bonferroni method when significant main or interaction effects were observed. The performance data and the change in BLa were analyzed using a 2-tailed, paired t test. The accepted level of significance was $P < .05$. The effect sizes (partial eta squared [η^2]) were determined from the analysis of variance (SSeffect/[SSeffect + SSresidual]) and t test ($t^2[/t^2 + \text{df}]$) outputs.

Results

The 25-Minute Passive Period

No changes were evident in the T_{core} at the baseline (37.4°C [0.6°C] vs 37.5°C [0.5°C]; $P = .84$) but, throughout the passive period, there were disparate changes over time ($F_{9,45} = 4.9$, $P < .01$), with higher values recorded in HEAT (Δ0.54°C [0.74°C]) compared with CON (Δ–0.93°C [1.15°C]) (condition, $F_{1,5} = 15.5$, $P = .01$, $\eta^2 = .38$; interaction, $F_{9,45} = 6.8$, $P < .01$). Post hoc analyses showed that the T_{core} was higher in HEAT at 20 ($P = .01$) and 25 ($P < .01$) minutes (Figure 1A). The T_{sk} also changed over time ($F_{9,45} = 65.1$, $P < .01$) and differed between conditions ($F_{1,5} = 25.1$, $P < .01$, $\eta^2 = .95$; interaction, $F_{9,45} = 4.3$, $P < .01$). Specifically, the T_{sk} was higher in HEAT versus CON at 20 ($P < .01$) and 25 minutes ($P = .01$) (Figure 1B).

In terms of the perceptual response, TC changed over time ($F_{9,45} = 9.5$, $P < .01$), with the responses being higher in HEAT versus CON ($F_{9,45} = 9.5$, $P < .01$, $\eta^2 = .70$); however, no interaction effect was evident ($F_{9,45} = 2.1$, $P = .053$). The within-condition effects for TC showed that every time-point throughout the intervention was increased in HEAT (all Ps < .01 vs pre), while in CON, the values were only different from pre at 5 ($P < .01$) and 10 ($P < .01$) minutes. TS also changed over time ($F_{9,45} = 2.2$, $P = .04$), with the responses being higher in HEAT versus CON ($F_{1,5} = 15.9$, $P = .01$, $\eta^2 = .42$; interaction, $F_{9,45} = 7.2$, $P < .01$). Specifically, TS was higher in HEAT at 10 ($P < .01$), 15 ($P < .01$), 20 ($P < .01$), and 25 ($P < .01$) minutes. The within-condition effects for TS showed that every time-point throughout the intervention was increased in HEAT (all Ps < .01 vs pre), while in CON, the values were only different from pre at 5 ($P < .01$), 10 ($P = .048$), and 15 ($P = .02$) minutes (Table 1).

TT Performance

Rowing performance was faster in HEAT versus CON (433.1 [12.7] s vs 437.9 [14.4] s, Δ1.1%, $t = 4.3$, $P < .01$, $\eta^2 = .92$; Figure 2). No differences were observed in maximum HR (180 [6.7] bpm vs 178 [9] bpm; $t = 1.07$, $P = .31$) or the change in BLa (Δ10.27 [1.68] mmol/L vs 9.77 [2.24] mmol/L; $t = 1.08$, $P = .31$).

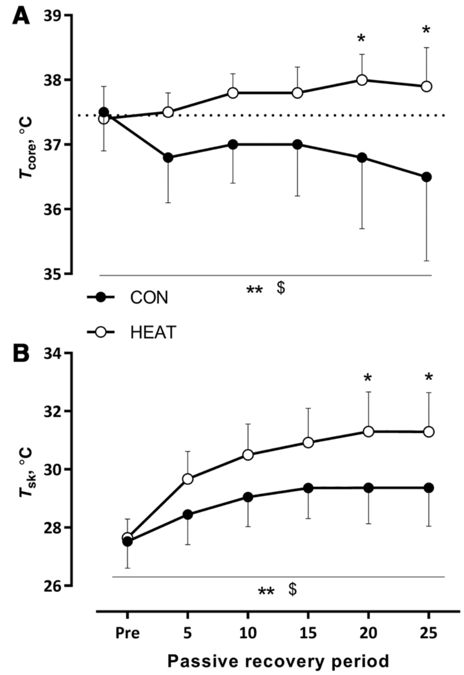

Figure 1 — Measurement of core (T_{core}, A) and mean skin temperature (T_{sk}, B) at baseline and throughout the 25-minute intervention period. CON indicates participants wore a standardized tracksuit top; HEAT, participants wore an externally heated jacket. *$P < .05$ versus the same time point in CON. **P < .05 condition effect. $P < .05 interaction effect.

Discussion

The main aim of the present investigation was to understand the effect of using an external heating garment prior to rowing performance in a cool environment. The results show that the core and mean skin temperature were higher when using a heated jacket, and this led to a faster (1.1%) 2000-m rowing performance. These data are in line with other investigations, which have used thermal interventions in the time prior to exercise performance, akin to that of a holding area during competition. Thus, the present study supports the use of a heated jacket by competitive rowers to maintain core temperature prior to competition, in order to improve performance, particularly when ambient temperatures are low.

Relevance to Rowing Performance

This study addresses a period of time that should be viewed as an opportunity for applied sport and exercise science practitioners. To the authors' knowledge, there is no present literature that has investigated the effects of passive heating protocols used in the time between the end of an active warm-up and the beginning of rowing performance. Such a timeframe was adopted to replicate the marshalling area where rowers wait before a race, which, similar to swimming, is known to be an area insufficient to perform exercise.[4,5] Using the heated garment led to an improvement in 2000-m rowing performance by 1.1%, a magnitude that is deemed important, as improvements in performance of as little as 1% can increase the likelihood of positioning higher in a rowing race.[13] The improvement in rowing performance is similar to what has been seen previously in swimming (1.01%)[5] and is likely driven by the

Table 1 Thermal Comfort (TC) and Thermal Sensation (TS) at Baseline and Throughout the 25-Minute Intervention Period, Mean (SD)

	Standardized Tracksuit Top						Externally Heated Jacket					
	Pre	**5**	**10**	**15**	**20**	**25**	**Pre**	**5**	**10**	**15**	**20**	**25**
TC	−1.0 (0.7)	0.7 (0.7)*	0.6 (0.7)*	0.2 (0.9)	−0.4 (1.1)	−0.6 (1.3)	−1.0 (0.7)	1.5 (0.7)*	1.9 (0.7)*	2.0 (0.7)*	2.0 (0.7)*	2.0 (0.7)*
TS	−1.5 (1.0)	0.2 (0.6)*	−0.1 (0.6)*	0.0 (1.5)*	−0.3 (1.3)	−0.4 (1.5)	−1.7 (0.9)	1.3 (0.5)*	1.6 (0.7)*,#	1.7 (0.7)*,#	1.8 (0.6)*,#	1.8 (0.6)*,#

Note: Visual analog scale anchors for TC: −3, very uncomfortable; −2, uncomfortable; −1, just uncomfortable; 0, neutral; 1, just comfortable; 2, comfortable; 3, very comfortable. TS: −3, cold; −2, slightly cold; −1, cool; 0, neutral; 1, warm; 2, slightly hot; 3, hot.

*$P < .05$ versus pre. #$P < .05$ versus control.

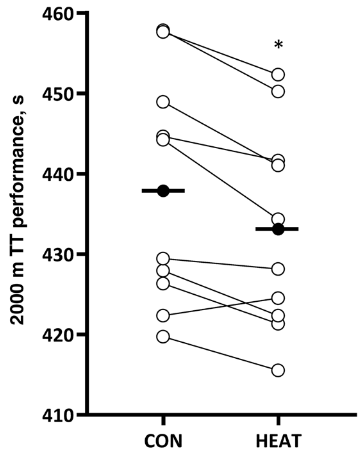

Figure 2 — Rowing performance. Individual data points are shown as unfilled circles, with the adjoining line between conditions, and the filled circles represent the mean response in each condition. CON indicates participants wore a standardized tracksuit top; HEAT, participants wore an externally heated jacket preexercise; TT, time trial. *$P < .01$ versus CON.

higher core and skin temperature (Figure 1) and the likely muscle temperature achieved when using the jacket.[5,8,18] The heated jacket caused an increase in the T_{core}, compared with a decline found when using the standardized tracksuit jacket, with an overall mean difference of 1.47°C. Such an increase in the T_{core} before competition is acknowledged to be a key determinant for endurance-/power-based events by facilitating increases in muscle fiber conduction velocity and muscle metabolism.[19,20] Furthermore, the ambient temperature is an important factor to be considered. When the heated jacket is used after warming up in a cool environment, the body temperature would be relatively lower compared with the same protocol if it was implemented in standard ambient conditions (18–20°C).[21] Thus, in a cooler environment, the time to reach a critical T_{core} would be delayed and performance would improve; however, at a standard ambient temperature, the use of a heated jacket might raise the T_{core} to critical levels and potentially reduce the capacity for exercise performance. In line with the physiological data, the ratings of thermal comfort and sensation improved when using the heated jacket (Table 1), suggesting that the participants felt more comfortable in this trial. Indeed, being warm causes widespread changes in the central nervous system[22] and increases perceptions of readiness to perform.[23] Thus, enhanced rowing performance with the heated jacket likely stemmed from changes in the physiological and psychological components.

Skin Temperature

Wearing the heated jacket during 25 minutes of passive rest following the active warm-up increased the T_{sk} on average by ~1.37°C compared with the control condition. Although the present study did not directly measure muscle temperature, it is likely that it would have increased, at least to some extent, when using the heated jacket.[8,24] It should be noted that the skin temperature measurement sites in the present study were located on the upper (chest and forearm) and lower body (calf), such that the use of an equation to estimate muscle temperature[25] is invalid. These sites were selected to capture the thermal effects of the heated jacket. Yet, the procedural difficulties associated with directly measuring muscle temperature at these sites, such as avoiding the circulatory anatomy, may make recording muscle temperature at the upper body more difficult. Taken together, the increased T_{sk} and T_{core} clearly demonstrates that the participants were hotter when using the heated jacket, and we speculate that this maintained the temperature of the underlying muscle. Given that a muscle temperature difference of ~0.3°C is known to alter performance,[8] increases in upper-body temperature with the use of the heated jacket, in part, likely explain the positive effect on subsequent rowing performance.

Most of the positive properties of warming up have been accredited to mechanisms relating to temperature regulation.[26] The relationship between muscle function and temperature is well recognized.[27–29] Thus, the maintenance of an increased muscle temperature from a warm-up is essential for attaining an optimal performance. Increased temperature improves performance due to a number of factors, including the change in the force–velocity relationship, increased transmission rate of nerve impulses, decreased stiffness of joints and muscles, and increased high-energy phosphate degradation, glycolgenolysis, and glycolysis.[26] Additionally, the likely improved muscle temperature when using the heated jacket would suggest that muscle-fiber conduction velocity is increased and is a potential mechanism contributing to the enhancement in performance.[27] Heightened muscle temperatures have also been related to the rise of myosin adenosine triphosphatase (ATP) activity, improving the rate of ATP turnover and calcium sequestration by the sarcoplasmic reticulum.[30,31] Collectively, these physiological variations confirm why an increased power output is reached and could be linked to higher muscle temperatures. As power output is a key influence in rowing performance, responsible for the ability to produce driving force, it is essential that temperature be upheld throughout the transition period prior to competition.[14]

Presently, there is no technique available to assist thermal maintenance during rowing competitions. Therefore, rowers potentially compete with suboptimal thermal profiles, as warm-ups are generally completed from anywhere between 20 and 25 minutes prior to racing. This is far from the optimal recommendation of between 5 and 10 minutes between the cessation of the warm-up and a race.[26] However, because of competition time constraints and the absence of warm-up facilities in marshalling areas, improving warm-up time is not possible. Durations that are longer than the optimal time to compete would result in a disadvantageous thermal profile, which we speculate to be the primary variable for enhancement when using the heated jacket in the present study. We show that the absence of thermal manipulation leads to the muscle contractile properties generating less powerful and slower contractions, as indicated by our slower performance times in the control condition.[28,32] Consequently, rowers might start a race in a suboptimal physical condition, thereby reducing possibilities of accomplishing a peak performance. Historically, research has suggested that females experience higher cardiovascular or thermal strain compared with men during exercise in the heat,[33] which would have implications for passive heating protocols. Such differences were related to group variations in body size, fitness, and environmental conditions. However, more recent evidence suggests that, across most activities and environments, it does not appear that women are at any disadvantage when exercising in the heat compared with men of similar age, fitness, and overall health,[34] making the present findings applicable to female rowers also. It should be noted, however, that fluctuations in the T_{core} across the menstrual cycle[35,36] could affect thermoregulation and potentially the effectiveness of a passive heating protocol. Nonetheless, our data suggest that an active warm-up, combined with a passive heating protocol, can offset such attenuations in temperature during the transition period and significantly improve 2000-m rowing performance in a cool environment.

Limitations

The method of T_{core} assessment in the present study has been shown to be confounded by convection and inaccuracies at higher temperatures, in comparison with other methods.[37] Despite this, we are confident in the data presented. The temperatures were never deemed to be "high," and disparate responses are reported; thus, if a more accurate method was used, the differences would have likely been more pronounced. Furthermore, showing a change with aural temperature demonstrates the strength of the hyperthermic stimulus generated by the jacket. Furthermore, we measured the responses during a passive period, so heating and cooling is not going to be profoundly influenced by convection (ie, no body movement) or large changes in blood circulation to the muscles under the heating jacket, which would happen if they were exercising. Thus, it is most likely that conductive heating and cooling was elicited during the intervention period. To address some of these points, further research is required to determine the optimal strategy for passive heating protocols, including the location of the heating elements embodied into a garment; garment temperature; the muscle groups that are studied; the effect of a harsher environment, including wind (convection); and the length of time the garments should be worn.

Practical Applications

The present study supports the use of a heated jacket by competitive rowers to maintain a thermal profile prior to competition, in order to improve performance, particularly when ambient temperatures are low. The findings reported here may be applicable to sports that experience delays post-warm-up, in particular events that are frequently performed in low ambient temperatures.

Conclusion

This study demonstrates that, after an active warm-up, 25 minutes of passive rest with the application of an externally heated jacket leads to a significant and relevant enhancement in 2000-m single scull rowing performance in a cool environment. This study presents the first practical application of heated garments in rowing and longer duration performance in low ambient temperatures. These data offer rowers a protocol to maintain body temperature throughout the unavoidable delay from the end of an active warm-up to the start of a race. The findings reported here may be applicable to sports that experience delays post warm-up and, in particular, events that are frequently performed in cool environments.

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