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1 **An external heating garment improves 2,000 m rowing performance in a cool**  
2 **environment**

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## Abstract

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**Purpose.** Rowers can be in marshalling areas for up to 20-25 minutes 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 standardised rowing warm-up can improve 2,000 m rowing performance. **Methods.** On two separate occasions, ten trained male rowers completed a standardised rowing warm-up, followed by 25 minutes of passive rest before a 2,000 m rowing time-trial (TT) on a rowing ergometer. Throughout the passive rest, participants wore either a standardised tracksuit top (CON) or an externally heated jacket (HEAT). The trials, presented in a randomised, cross-over fashion, were performed in a controlled environment (temperature, 8°C; humidity 50%). Rowing TT performance, core body and mean skin temperature, along with perceptual variables were measured. **Results.** During the 25 minute period, core body temperature increased in HEAT and decreased in CON ( $\Delta 0.54 \pm 0.74$  vs.  $-0.93 \pm 1.14^\circ\text{C}$ ;  $P = 0.02$ ). Additionally, mean skin temperature ( $30.22 \pm 1.03$  vs.  $28.86 \pm 1.07^\circ\text{C}$ ) was higher in HEAT vs. CON ( $P < 0.01$ ). In line with the physiological data, perceptual data confirmed that participants were more comfortable in HEAT vs. CON and subsequently, rowing performance was improved in HEAT compared to CON ( $433.1 \pm 12.7$  vs.  $437.9 \pm 14.4$  s,  $P = 0.002$ ). **Conclusion.** Our data demonstrate that an upper body external heating garment, worn following a warm-up, can improve rowing performance in a cool environment.

## Introduction

Rowing is a physiological demanding sport due to the recruitment of a large muscle mass and work rates near to rowers' maximal physical capacity<sup>1,2</sup>. Rowers possess large body dimensions and produce among the largest values of any athlete in specific parameters of physical fitness, involving those related to muscular and cardiorespiratory function<sup>3</sup>, 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 ~10-15 minutes before the start of a race and 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 decline in core temperature ( $T_{core}$ ) with longer transitions<sup>4</sup> and a reduction in this time has been found to attenuate the overall decline in  $T_{core}$ , significantly improving performance times<sup>5,6</sup>. 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 fibres, increased anaerobic metabolic capacity and nerve conduction enhancements in both the peripheral and central nervous system<sup>7</sup>. 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 followed by 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%)<sup>8</sup>. More specifically, a combination of an active swimming warm-up followed by use of an upper body passive heating device in the "call room", improved maintenance in core and muscle temperature and overall swimming performance to a similar extent<sup>5,9</sup>. 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 ( $\geq 5$  minutes), this is partly due to the fact that there are detrimental physiological factors which negatively impact performance in such circumstances. Gregson et al.<sup>10</sup> reported that following a passive warm-up which increased  $T_{core}$  to 38.0°C, significantly decreased the time to exhaustion at 70% of maximum aerobic capacity. Similarly, the same authors also observed warming-up passively, significantly decreases high-intensity intermittent exercise time to exhaustion at an ambient temperature (21.7°C)<sup>11</sup>. 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<sup>10</sup>. However, at a lower ambient temperature (5°C), a significantly higher heat-storage capacity exists compared to standard ambient conditions (18-20°C)<sup>12</sup>. 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 2,000 m single scull rowing performance. It was hypothesised that the heated jacket would improve performance in a cool environment by attenuating the decline in body temperature.

## Methods

### *Participants*

Ten trained male rowers participated in this study (age,  $24.1 \pm 2.89$  years; stature,  $1.85 \pm 0.4$  m; body mass,  $77.61 \pm 5.49$  kg). The population was defined as a rower who regularly competes in key regional or national tournaments and for the sample studied, rowers competed for  $4 \pm 2$  years and trained  $5 \pm 1$  times a week for a total of  $7 \pm 3$  hours. A sample size of 10 was calculated using a change in mean 2,000 m rowing TT performance, a crossover design in a similar population and the SD of non-tapered performance times ( $\pm 23.4$  s). A statistical power of 0.8 and the smallest worthwhile improvement in performance of 1%<sup>13</sup> was used (v18 Mini Tab LL, Microsoft, PEN, USA). None of the participants supplemented their diets with any putative ergogenic aid for six months before the start of the study. All participants were explained the experimental procedures, potential benefits, the value of likely findings and associated risks, before providing informed consent to participate. Participants were asked to avoid the consumption of caffeine and alcohol and refrain any vigorous exercise 24 hours before all testing. 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, randomised and counterbalanced experimental design. Each participant was required to visit the environmental chamber (TIS Services, Alton, Hampshire, UK) on three separate occasions, with each session  $\sim 7$  days apart. Trials were performed at the same time of day ( $\pm 1$  hour) to minimise circadian effects. Before the two experimental sessions participants were familiarised with the exercise protocol and initial measurements were taken (age, stature and body mass). Participants then entered the environmental chamber, with the temperature ( $8^{\circ}\text{C}$ ) and humidity (50%) controlled to reflect common morning conditions experienced at the start of the competitive UK outdoor rowing season (March). During each visit, participants completed a 10 minute standardised rowing warm-up<sup>14</sup>, 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, participants wore a pair of standardised tracksuit bottoms with a standardised tracksuit top (CON) or, an externally heated jacket (HEAT; Powerlet rapidFIRE Proform Heated Jacket Liner, Warren, MI, USA). Following the passive rest, clothing was removed and a 2,000 m TT was performed on a rowing ergometer (Concept2, Nottingham, UK).

### *Procedure*

Participants arrived at the environmental chamber after consuming a meal typically  $\sim 2$  hours prior to testing. Upon arrival, following baseline measurements of stature and body mass (Seca Ltd, Birmingham, UK), a calibrated aural thermistor (Grant Instruments, Cambridge, UK), was inserted into the participant's right auditory canal to estimate  $T_{\text{core}}$ . The thermistor was securely taped into position and insulated with cotton wool<sup>15</sup>, before a headband was fitted to maintain placement. Additionally, wired skin thermistors (Grant Instruments) were then attached to the forearm ( $T_{\text{Forearm}}$ ), chest ( $T_{\text{Chest}}$ ) and calf ( $T_{\text{Calf}}$ ) for the calculation of mean skin temperature ( $T_{\text{Sk}}$ ;  $T_{\text{Sk}} = 0.5 \times T_{\text{Chest}} + 0.36 \times T_{\text{Calf}} + 0.14 \times T_{\text{Forearm}}$ )<sup>16</sup>. 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, UK) that sampled data in 10 s epochs. A heart rate (HR) monitor was also fitted (Polar FT1; Polar Electro Oy, Kempele, Finland) prior to entering the chamber.

156 Once participants entered the environmental chamber, they were seated for a 10 minute  
157 stabilisation period, during this time participants wore a standardised tracksuit comprising of a  
158 zipped-up tracksuit top and trouser bottoms, both consisting of a single layer of nylon material  
159 with minimal insulation. Following the stabilisation period, baseline measurements were  
160 recorded beginning with a capillary blood sample (20 ml) from the earlobe to measure blood  
161 lactate (BLa) using a calibrated, automated system (Biosen 5030, EKF Industrie, Elektronik  
162 GmbH, Barleben, Germany). Additionally,  $T_{\text{core}}$ ,  $T_{\text{Chest}}$ ,  $T_{\text{Calf}}$ ,  $T_{\text{Forearm}}$ , and HR were recorded,  
163 as well as thermal comfort (TC) and thermal sensation (TS) using visual analogue scales<sup>17</sup>. The  
164 number range for both scales was consistent but anchors varied (TC, -3 very uncomfortable,  
165 -2 uncomfortable, -1 just uncomfortable, 0 neutral, 1 just comfortable, 2 comfortable, 3 very  
166 comfortable; TS, -3 cold, -2 slightly cold, -1 cool, 0 neutral, 1 warm, 2 slightly hot, 3 hot).  
167 Participants then completed a standardised 10 minute rowing warm-up using 18-20 strokes per  
168 minute<sup>14</sup>. Immediately after the warm-up, participants were seated for 25 minutes simulating  
169 the 'marshalling period' between the warm-up and the beginning of a rowing race. Participants  
170 wore a long sleeve t-shirt, standardised tracksuit trouser bottoms and CON or HEAT; both  
171 jackets' insulations were similar when unheated. The heated jacket (Powerlet rapidFIRE  
172 Proform) was chosen because of the optimal coverage of the torso and arms with the heating  
173 elements in comparison to other varieties. The key upper body muscle groups (lower deltoids,  
174 tricep brachii, pectoralis major and the latissimus dorsi) used for rowing were covered by the  
175 heating elements which were powered by 12 V, 10 A power transformers enabling capacity of  
176 105 W. The jacket's stretch panels allowed for optimal heat transfer, as the material is  
177 maintained close to the body, thus decreasing convection, whilst allowing movement. The  
178 maximum temperature of the heating elements was 50°C but  $T_{\text{sk}}$  is known to be lower<sup>5</sup>. The  
179 long sleeve t-shirt was worn under the jacket to eliminate the likelihood of burning and ratings  
180 of TC and TS were made throughout the entire protocol. Participants were asked to ensure the  
181 jacket felt 'comfortable ( $\leq 2$ )' and 'hot ( $\leq 3$ )', if the participant felt 'uncomfortable ( $\geq -2$ )' the  
182 heat stimulus was reduced. As the garment is used for sub-zero conditions, a maximum level  
183 of possible heating was not encroached upon. Over the duration of the 25 minute period, all  
184 temperature related measurements were recorded every 5 minutes. Following the passive  
185 period, tracksuits were removed, and participants performed the 2,000 m rowing TT,  
186 replicating the single scull event. Participants were instructed to complete the distance in the  
187 fastest possible time and were blinded to feedback. Performance was recorded as the time to  
188 completion (s) with HR measured throughout (every 30 s) and BLa measured immediately post.

189

### 190 *Data analysis*

191 Data are presented as mean  $\pm$  SD unless stated otherwise and all data were analysed using  
192 GraphPad Prism (v7.04, GraphPad Software, San Diego, CA, USA). Prior to analyses,  
193 normality of data was assessed using the Kolmogorov-Smirnov test (v26, SPSS, IBM  
194 Cooperation, Armonk, NY, USA). Parameters measured throughout the passive period were  
195 analysed using a two-way, repeated-measures ANOVA (Condition [2], time [6]) with multiple  
196 comparisons corrected using the Bonferroni method when significant main or interaction  
197 effects were observed. Performance data, and the change in BLa, were analysed using a two-  
198 tailed, paired T-test. The accepted level of significance was  $P < 0.05$ . Effect sizes (partial eta  
199 squared [ $\eta^2$ ]) were determined from the ANOVA ( $SS_{\text{effect}}/[SS_{\text{effect}}+SS_{\text{residual}}]$ ) and T-test  
200 ( $t^2/[t^2 + df]$ ) outputs.

201

202

## 202 **Results**

### 203 *25 minute passive period*

204 No changes were evident in  $T_{\text{core}}$  at baseline ( $37.4 \pm 0.6$  vs.  $37.5 \pm 0.5^\circ\text{C}$ ;  $P = 0.838$ ) but  
205 throughout the passive period there were disparate changes over time ( $F_{9,45} = 4.9$ ,  $P < 0.001$ ),

206 with higher values recorded in HEAT ( $\Delta 0.54 \pm 0.74^\circ\text{C}$ ) compared to CON ( $\Delta -0.93 \pm 1.15^\circ\text{C}$ )  
207 (condition,  $F_{1,5} = 15.5$ ,  $P = 0.011$ ,  $\eta^2 = 0.38$ ; interaction,  $F_{9,45} = 6.8$ ,  $P < 0.001$ ). Post hoc  
208 analyses showed that  $T_{\text{core}}$  was higher in HEAT at 20 ( $P = 0.008$ ) and 25 mins ( $P = 0.001$ )  
209 (Figure 1A).  $T_{\text{sk}}$  also changed over time ( $F_{9,45} = 65.1$ ,  $P < 0.001$ ) and differed between  
210 conditions ( $F_{1,5} = 25.1$ ,  $P = 0.004$ ,  $\eta^2 = 0.95$ ; interaction,  $F_{9,45} = 4.3$ ,  $P < 0.001$ ). Specifically,  
211  $T_{\text{sk}}$  was higher in HEAT vs. CON at 20 ( $P < 0.012$ ) and 25 mins ( $P = 0.013$ ) (Figure 1B).

212

213 In terms of the perceptual response, TC changed over time ( $F_{9,45} = 9.5$ ,  $P < 0.001$ ) with  
214 responses being higher in HEAT vs. CON ( $F_{9,45} = 9.5$ ,  $P < 0.001$ ,  $\eta^2 = 0.70$ ), however, no  
215 interaction effect was evident ( $F_{9,45} = 2.1$ ,  $P = 0.053$ ). Within condition effects for TC showed  
216 that every time point throughout the intervention was increased in HEAT (all  $P < 0.0001$  vs.  
217 pre), whilst in CON, values were only different from pre at 5 ( $P < 0.001$ ) and 10 ( $P = 0.001$ )  
218 mins. TS also changed over time ( $F_{9,45} = 2.2$ ,  $P = 0.037$ ) with responses being higher in HEAT  
219 vs. CON ( $F_{1,5} = 15.9$ ,  $P = 0.011$ ,  $\eta^2 = 0.42$ ; interaction,  $F_{9,45} = 7.2$ ,  $P < 0.001$ ). Specifically, TS  
220 was higher in HEAT at 10 ( $P = 0.003$ ), 15 ( $P = 0.003$ ), 20 ( $P < 0.001$ ) and 25 mins ( $P < 0.001$ ).  
221 Within condition effects for TS showed that every time point throughout the intervention was  
222 increased in HEAT (all  $P < 0.0001$  vs. pre), whilst in CON, values were only different from  
223 pre at 5 ( $P = 0.003$ ), 10 ( $P = 0.048$ ) and 15 ( $P = 0.020$ ) mins (Table 1).

224

#### 225 *TT performance*

226 Rowing performance was faster in HEAT vs. CON ( $433.1 \pm 12.7$  vs.  $437.9 \pm 14.4$  s,  $\Delta 1.1\%$ ,  $t$   
227  $= 4.3$ ,  $P = 0.002$ ,  $\eta^2 = 0.92$ ; Figure 2). No differences were observed in maximum HR ( $180 \pm$   
228  $6.7$  vs.  $178 \pm 9$  bpm;  $t = 1.07$ ,  $P = 0.311$ ) or the change in BLa ( $\Delta 10.27 \pm 1.68$  vs.  $9.77 \pm 2.24$   
229  $\text{mmol}\cdot\text{L}$ ;  $t = 1.08$ ,  $P = 0.306$ ).

230

231

### 231 **Discussion**

232 The main aim of the present investigation was to understand the effect of using an external  
233 heating garment prior to rowing performance in a cool environment. The results show that core  
234 and mean skin temperature were higher when using a heated jacket and this led to a faster  
235 (1.1%) 2,000 m rowing performance. These data are in line with other investigations which  
236 have used thermal interventions in the time prior to exercise performance, akin to that of a  
237 holding area during competition. Thus, the present study supports the use of a heated jacket by  
238 competitive rowers to maintain core temperature prior to competition, in order to improve  
239 performance, particularly when ambient temperatures are low.

240

#### 241 *Relevance to rowing performance*

242 This study addresses a period of time that should be viewed as an opportunity for applied sport  
243 and exercise science practitioners. To the authors' knowledge there is no present literature that  
244 has investigated the effects of passive heating protocols used in the time between the end of an  
245 active warm-up and the beginning of rowing performance. Such a timeframe was adopted to  
246 replicate the marshalling area where rowers wait before a race, which similar to swimming, is  
247 known to be an area insufficient to perform exercise<sup>4,5</sup>. Using the heated garment led to an  
248 improvement in 2,000 m rowing performance by 1.1%, a magnitude which is deemed important  
249 as improvements in performance of as little as 1% can increase the likelihood of positioning  
250 higher in a rowing race<sup>13</sup>. The improvement in rowing performance is similar to what has been  
251 seen previously in swimming (1.01%)<sup>5</sup> and is likely driven by the higher core and skin  
252 temperature (Figure 1) and likely muscle temperature achieved when using the jacket<sup>5,8,18</sup>. The  
253 heated jacket caused an increase in  $T_{\text{core}}$ , compared to a decline found when using the  
254 standardised tracksuit jacket, with an overall mean difference of  $1.47^\circ\text{C}$ . Such an increase in  
255  $T_{\text{core}}$  before competition, is acknowledged to be a key determinant for endurance/power based



256 events by facilitating increases in muscle fibre conduction velocity and muscle metabolism<sup>19,20</sup>.  
257 Furthermore, the ambient temperature is an important factor to be considered. When the heated  
258 jacket is used after warming up in a cool environment, body temperature would be relatively  
259 lower compared to if the same protocol was implemented in standard ambient conditions (18-  
260 20°C)<sup>21</sup>. Thus, in a cooler environment, the time to reach a critical  $T_{core}$  would be delayed and  
261 performance improves, however, at a standard ambient temperature, the use of a heated jacket  
262 might raise  $T_{core}$  to critical levels and potentially reduce capacity for exercise performance. In  
263 line with the physiological data, ratings of thermal comfort and sensation improved when using  
264 the heated jacket (Table 1), suggesting that participants felt more comfortable in this trial.  
265 Indeed, being warm causes widespread changes in the central nervous system<sup>22</sup> and increases  
266 perceptions of readiness to perform<sup>23</sup>. Thus, enhanced rowing performance with the heated  
267 jacket, likely stemmed from changes in physiological and psychological components.

268

### 269 *Skin Temperature*

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

285

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

302

303 Presently, there is no technique available to assist thermal maintenance during rowing  
304 competitions. Therefore, rowers potentially compete with sub optimal thermal profiles, as  
305 warm-ups are generally completed from anywhere between 20-25 minutes prior to racing. This

306 is far from the optimal recommendation of between 5-10 minutes between cessation of warm-  
307 up and a race<sup>26</sup>. However, because of competition time constraints and the absence of warm-  
308 up facilities in marshalling areas, improving warm-up time is not possible. Durations which  
309 are longer than the optimal time to compete, would result in a disadvantageous thermal profile,  
310 which we speculate to be the primary variable for enhancement when using the heated jacket  
311 in the present study. We show that the absence of a thermal manipulation leads to the muscle  
312 contractile properties generating less powerful and slower contractions, as indicated by our  
313 slower performance times in the control condition<sup>28,32</sup>. Consequently, rowers might start a race  
314 in a sub optimal physical condition, thereby reducing possibilities of accomplishing a peak  
315 performance. Historically, research has suggested that females experience higher  
316 cardiovascular or thermal strain compared to men during exercise in the heat<sup>33</sup>, which would  
317 have implications for passive heating protocols. Such differences were related to group  
318 variations in body size, fitness and environmental conditions. However, more recent evidence  
319 suggests that across most activities and environments, it does not appear that young, healthy  
320 women are at any disadvantage when exercising in the heat compared to men of similar age,  
321 fitness and overall health<sup>34</sup>, making the present findings applicable to female rowers also. It  
322 should be noted, however, that fluctuations in  $T_{\text{core}}$  across the menstrual cycle<sup>35,36</sup> could affect  
323 thermoregulation and potentially the effectiveness of a passive heating protocol. Nonetheless,  
324 our data suggest that an active warm-up, combined with a passive heating protocol, can offset  
325 such attenuations in temperature during the transition period and significantly improve 2,000  
326 m rowing performance in a cool environment.

327

#### 328 *Limitations*

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

343

#### 344 *Practical applications*

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

350

#### 351 *Conclusion*

352 This study demonstrates that after an active warm-up, 25 minutes of passive rest with the  
353 application of an externally heated jacket, leads to a significant and relevant enhancement in  
354 2,000 m single scull rowing performance in a cool environment. This study presents the first  
355 practical application of heated garments in rowing and longer duration performance in low

356 ambient temperatures. These data offer rowers a protocol to maintain body temperature  
357 throughout the unavoidable delay from the end of an active warm-up to the start of a race. The  
358 findings reported here may be applicable to sports that experience delays post warm-up and in  
359 particular, events which are frequently performed in cool environments.

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453

### Table & Figure Legends

454 **Table 1.** Thermal comfort and thermal sensation at baseline and throughout the 25 minute  
455 intervention period.

456

457 **Figure 1.** Measurement of core ( $T_{\text{core}}$ , A) and mean skin temperature ( $T_{\text{sk}}$ , B) at baseline and  
458 throughout the 25 minute intervention period. \*\* =  $P < 0.05$  condition effect, \$ =  $P < 0.05$   
459 interaction effect and \* =  $P < 0.05$  vs. the same time point in CON.

460

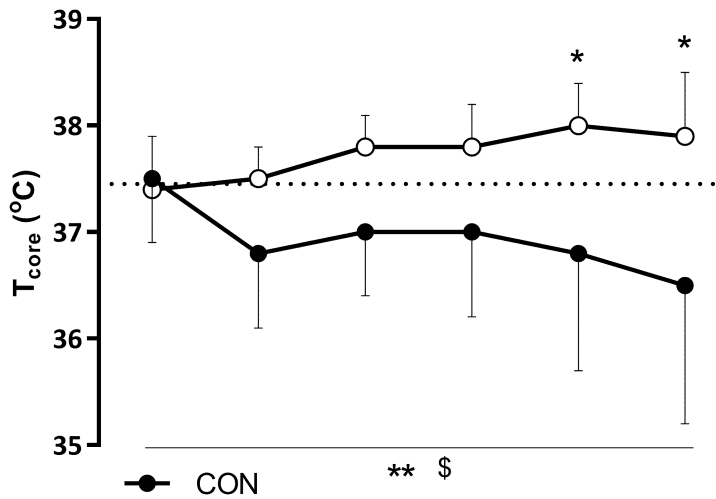
461 **Figure 2.** Rowing performance; individual data points are shown as unfilled circles with the  
462 adjoining line between conditions and the filled circles represent the mean response in each  
463 condition. \* =  $P = 0.002$  vs. CON.

**Table 1.** Thermal comfort and thermal sensation at baseline and throughout the 25 minute intervention period.

Control						Experimental					
Thermal Comfort (TC)											
Pre	5	10	15	20	25	Pre	5	10	15	20	25
$-1.0 \pm 0.7$	$0.7 \pm 0.7^*$	$0.6 \pm 0.7^*$	$0.2 \pm 0.9$	$-0.4 \pm 1.1$	$-0.6 \pm 1.3$	$-1.0 \pm 0.7$	$1.5 \pm 0.7^*$	$1.9 \pm 0.7^*$	$2.0 \pm 0.7^*$	$2.0 \pm 0.7^*$	$2.0 \pm 0.7^*$
Thermal Sensation (TS)											
Pre	5	10	15	20	25	Pre	5	10	15	20	25
$-1.5 \pm 1.0$	$0.2 \pm 0.6^*$	$-0.1 \pm 0.6^*$	$0.0 \pm 1.5^*$	$-0.3 \pm 1.3$	$-0.4 \pm 1.5$	$-1.7 \pm 0.9$	$1.3 \pm 0.5^*$	$1.6 \pm 0.7^{*#}$	$1.7 \pm 0.7^{*#}$	$1.8 \pm 0.6^{*#}$	$1.8 \pm 0.6^{*#}$

Visual analogue scale anchors: 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. \*  $P < 0.05$  vs. Pre; # =  $P < 0.05$  vs. CON.



**A****B**