The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes

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Submitted 10 October 2007; accepted in final form 23 April 2008

The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes. J Appl Physiol 105: 37–43, 2008. First published April 24, 2008; doi:10.1152/japplphysiol.01084.2007.—The purpose of this study was to examine the effectiveness of reducing core temperature in postexercise hyperthermic subjects and to assess if hand cooling (HC) improves subsequent timed distance performance. Following a detailed measurement check on the use of insulated auditory canal temperature (Tac), eight wheelchair (WA) and seven able-bodied (AB) athletes performed two testing sessions, comprising a 60-min exercise protocol and 10-min recovery period, followed by a performance trial (1 km and 3 km for WA and AB, respectively) at 30.8°C (SD 0.2) and 60.6% (SD 0.2) relative humidity. In a counterbalanced order, HC and no-cooling condition was administered during the 10-min recovery period before the performance trial. Nonsignificant condition × time interactions for Tac of AB (F15.75 = 1.5, P = 0.14) and AB (F15.60 = 1.2, P = 0.32) confirmed that the exercise-induced changes (Δ) in Tac were similar before each intervention. However, the exercise-induced increase was evidently greater in AB compared with WA (2.0 vs. 1.3°C change, respectively). HC produced ΔTac of −0.4°C (SD 0.4) and −1.2°C (SD 0.2) in comparison (WA and AB, respectively), and simple-effects analyses suggested that the reductions in Tac were noteworthy after 4 min of HC. HC had an impact on improving AB performances by −4.0 s (SD 11.5) (P < 0.05) and WA by −20.5 s (SD 24.2) (P > 0.05). In conclusion, extraction of heat through the hands was effective in lowering Tac in both groups and improving 3-km performance in the AB athletes and trends toward positive gains for the 1-km performance times of the WA group.

wheelchair sports; aural temperature; intestinal temperature; reliability; cooling strategies

A VARIETY OF METHODS for cooling, such as cooling vests (9, 13), whole body cooling (16, 29), and hand/foot cooling (10, 18), have been administered among several sporting populations in recent years. Positive effects of cooling have been reported for endurance capacity (10, 13), reduced thermal strain (11, 28), and improved 5-km performance (26). The application of these methods is suitable for some sports participants but not others. For example, the start time of a top-class tennis game is often not known, making the opportunity for precooling exposure before the start of play difficult. Yet, due to the nature of the activity, where there is a succession of exercise and rest periods, hand cooling (HC) may become a practical method.

HC applied to military personnel working in hot environments has been found to reduce rest times and lengthen work times (14, 18). Grahn et al. (10) concluded that heat removal through the hand is an efficient and effective method to provide a substantial performance benefit in thermally stressed conditions. Hsu et al. (15) found that HC lowered tympanic temperature, lactate concentration, and oxygen uptake during cycling exercise and reduced the time to complete a 30-km time trial. Little data exist relating to cooling strategies for wheelchair-bound populations (11, 11, 28) even though it is well known that spinal cord-injured (SCI) athletes are less-effective thermoregulators than able-bodied athletes in hot environments (23), and paralympic competitions are often held in hot environments. To our knowledge there are no published data that address the use of HC in wheelchair athletes. This lack of information hinders the development of guidelines for future athletic competitions for paralympic athletes who may be competing at the Beijing Paralympic Games or other tropical regions.

The research concerned with wheelchair-bound populations (11, 11, 28) has involved an array of methods to measure the thermoregulatory responses to cooling. These methods have included tympanic/rectal probes and the use of ingestible telemetry pills (1, 11, 28). Considerable differences exist in terms of the reliability and validity of these measurements in wheelchair-dependent persons (7). Price (23) favored the use of the insulated auditory canal temperature (Tac) method for persons with a spinal cord injury. However, ingestible temperature sensor capsules have been used in the most recent of the three aforementioned studies (28). It is important to describe the agreement between temperature measurements in the lower body using an ingestible thermometer and those in the upper body using an insulated auditory canal-insulated auditory canal thermometer, since the latter method is reusable and less expensive.

The primary purpose of the study was to examine the effectiveness of reducing core temperature in postexercise hyperthermic subjects and to assess if such cooling improves subsequent timed-distance performance. The secondary purpose was to assess any differences in cooling effectiveness between able-bodied and wheelchair subjects. We hypothe-
sized that 1) HC will be an effective method of reducing exercise-induced hyperthermia for both wheelchair and able-bodied athletes, and 2) the thermoregulatory and physiological effects of HC in both groups will lead to an improvement in subsequent exercise performance compared with no HC (NC). Since the main experimental procedure involves the use of $T_{\text{ac}}$, we also supplemented our investigation with an exploration of the reliability and agreement between intestinal and $T_{\text{ac}}$ measurements during an intermittent exercise protocol performed by athletes with spinal cord injuries.

**MATeRIAL AND METHODS**

In this study, 15 able-bodied and wheelchair volunteers undertook a 60-min intermittent exercise protocol, followed by a 10-min resting recovery period, before completing a set-distance exercise challenge as fast as possible. This procedure was conducted twice on separate days, once with HC in 10°C water, and once without.

**Participants**

Fifteen participants gave informed consent to participate in the study, which was approved by the University Ethics Committee. The group comprised eight trained wheelchair tennis players (WA; 2 quadriplegic and 6 from the open division wheelchair tennis classifications) and seven male able-bodied (AB) sport science students. All were physically trained and exercised regularly 4–5 days/wk (Table 1). Participants visited the laboratory on three separate occasions. During the first visit to the laboratory, after body mass was measured, a continuous incremental protocol was used to determine peak oxygen uptake ($V_{\text{O}}_{2\text{peak}}$) using either a wheelchair ergometer (Bromakin) or Monark cycle ergometer (Ergomedic, 814E, Varberg, Sweden). For the WA group, this test involved increases in external work—an initial propulsion speed of 1.6 m/s at a freely chosen push frequency. For the AB, this test involved increases in external workloads of 12 W every 1 min from an initial workload of 120 W at a crank rate of 60 rpm.

Five of the WA ingested a telemetry pill ($T_{\text{pill}}$; HQ) for the measurement of gastrointestinal temperature, an index of core body temperature, 10 h before the experiment, in accordance with Sparling et al. (25), to ensure reliable values before the second and third testing sessions. The $T_{\text{pill}}$ transmits a temperature signal, relative to the surrounding gastrointestinal temperature ($T_{\text{intestinal}}$), by radio wave to a hand-held recorder. Five wheelchair and seven able-bodied athletes participated in the comparative study to examine the effectiveness of HC and completed the endurance time trials. All 12 participants were used to address the relationship between the final $T_{\text{ac}}$ following the 60-min exercise in the heat and the delta change following 10 min of HC (Table 2).

**Experimental Conditions**

The environmental chamber was maintained at 30.8°C (SD 0.2) and 60.6 (0.2)% relative humidity. Each participant completed the same 60-min steady-state intermittent protocol on the CYCLE (AB) and WERG (WA), consisting of five 10-min blocks at 50% peak power output ($W_{\text{peak}}$), separated by 2 min passive rest. Each test was performed at the same time of day, separated by 7–10 days in a counterbalanced order. A standardized 100 ml of water (room temperature) was provided during the 2-min rest periods to keep each participant hydrated and replace sweat losses. This equated to a compulsory 500 ml consumed during the 60-min stage, before the performance time trial (10, 11); no fan was used. Following the initial 60 min of exercise, the HC condition involved 10 min recovery period while both hands were immersed to the wrist in containers of 10°C water (14, 18). The participants served as their own controls, and the second condition involved 10 min recovery with no cooling (NC) before the performance trial. The performance trial consisted of either a 1-km or 3-km trial with the instruction to complete the distance as fast as possible for the WA and AB group, respectively. The WA group used a wheelchair ergometer, and the AB group used a cycle ergometer.

**Prolonged Exercise Tests in the Heat**

After voiding the bladder, measurements before and after each test included body mass to support sweat loss calculations; clothing was weighed and measurement taken in minimal clothing to represent nude weight; fingertip capillary blood samples were taken for hemoglobin (Clndon HemoCue, HemoCue, Sheffield, UK) and hematocrit (Microcentrifuge, Hawksley hematocrit reader, Hawksley and Sons, Sussex, UK) to show changes in plasma volume (23). Skin thermistsors (Edale type EUL, Edale Instruments, Cambridge, UK) were attached on the chest, back, upper arm, lower arm, thigh, and calf, with transprose tape to record skin temperatures ($T_{\text{sk}}$) via a Grant Squirrel meter (Series 1250, Grant Instruments, Cambridge, UK). An aural thermistor (Edale medical thermisters, Edale Instruments) was positioned and secured in the auditory canal using tape and cotton wool to measure $T_{\text{ac}}$. Baseline measures were recorded after a 15-min period to allow stabilization of thermisters.

Measurements were taken at 5-min intervals during the 60-min protocol, and at 1-min intervals during the 10-min HC and NC recovery periods. Measurements included heart rate (HR); subjective measures for rating of perceived exertion [RPE (5)] and thermal

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**Table 1. Anthropometric and $V_{\text{O}}_{2\text{peak}}$ measures for both groups**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Disability/Level of Injury</th>
<th>Tennis Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>27.2 (6.9)</td>
<td>25.4 (4.2)</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>68.3 (17.9)</td>
<td>75.3 (10.0)</td>
</tr>
<tr>
<td>$V_{\text{O}}_{2\text{peak}}, l/min$</td>
<td>1.94 (0.71)</td>
<td>3.71* (0.6)</td>
</tr>
<tr>
<td>HR peak, beats/min</td>
<td>176 (31)</td>
<td>186 (12)</td>
</tr>
<tr>
<td>$W_{\text{peak}}, W$</td>
<td>81 (39)</td>
<td>262* (56)</td>
</tr>
<tr>
<td>50% $W_{\text{peak}}, W$</td>
<td>43 (21)</td>
<td>129* (25)</td>
</tr>
</tbody>
</table>

Values are means (SD). WA, wheelchair-trained athletes; AB, able-bodied athletes; $V_{\text{O}}_{2\text{peak}}$, peak oxygen uptake; HR, heart rate; $W_{\text{peak}}$, peak power output. *Significant difference, AB vs. WA group, at $P < 0.05$ level.
sensation [TS (27), where values of 0, 4 and 8 correspond to feeling unbearably cold, comfortable, and unbearably hot, respectively]; Tad and Tad. Mean Tad was calculated from the above mentioned sites.

For those wheelchair athletes who ingested a telemetry pill, the core temperature was also recorded at the intervals described above. The telemetry pills were factory calibrated but checked in a water bath against an electronic thermometer of known accuracy. Where inaccurate, the calibration of the telemetry pills were altered accordingly as described by Mittal et al. (21).

Data Analysis

Agreement between intestinal and insulated auditory canal temperature. Systematic differences between methods, repeated trials, and time during the exercise protocol were examined with a three-factor linear mixed model analysis (8). All three factors were analyzed as repeated measures in this model. Ninety-five percent confidence intervals (95% CI) were calculated for the differences between methods, repeated trials, and exercise time. Statistically significant interactions between exercise time and the other factors were examined with an interaction plot and described by calculating the rise in temperature per unit time in each trial. Since one of the factors in this particular analysis was time, multiple post hoc comparisons were deemed not to be appropriate (2, 19).

For description of random error between methods and repeated tests, the within-subjects SD, also known as the standard error of measurement (SEM) in the case of a reliability examination, and the 95% limits of agreement were calculated (3). Ninety-five percent confidence limits were also calculated for the above random error statistics.

If the random errors differed substantially from a Gaussian distribution and/or were found to be proportional to the size of the measured value, the raw data were logarithmically transformed and described with ratio-type statistics (e.g., coefficient of variation) rather than error statistics expressed in the actual units of measurement. The presence of such proportional error was investigated through inspection of Bland-Altman plots and the correlation exploration that was outlined by Nevill and Atkinson (22).

Error statistics, and the associated 95% CI, were compared with values that were deemed to be practically important. In terms of the method comparison, we delimit that a systematic bias between methods of greater than 0.1°C would be practically significant in affecting decisions made on an individual’s thermal status. This bias limit is also stipulated by the British Standard for clinical thermometers (6). Given that the limits of agreement describe the largest difference between methods that can be expected for any individual and that biological variation is inherent in our measurements, we deemed that this statistic should not be larger than ±0.3°C. In terms of reliability, we deemed that the test-retest measurement error of Tpill would be acceptable on the basis of a within-subjects SD <0.2°C. Using calculations based on a statistical power of 80%, it was estimated that this magnitude of random error would enable the detection in a future study of a 0.2°C change in body temperature using a feasible sample size of 16 participants (4).

HC study. Student's independent t-tests were used to identify any between group differences in anthropometric and physiological characteristics. The Tad measured over the initial 60-min exercise period and the 10-min recovery period were analyzed independently and also separately for each group. Within-measures 2 × 16 (condition × time) ANOVAs were used to analyze the Tad responses to exercise. Furthermore, a mixed measures 2 × 2 (group × condition) ANOVA was used to compare the final exercise Tad measured at 60 min. These analyses were used to confirm that the increases in Tad between the two exercise trials were not different, thus establishing a comparable baseline before the 10-min intervention. For the 10-min intervention period, separate within-measures 2 × 10 (condition × time) ANOVAs were used to compare differences in Tad. Pearson’s product-moment correlations were used to examine the relationships between the final exercise Tad measured at 60 min and the change (delta) in Tad over the 10 min intervention period. Finally, potential differences in 1-km and 3-km time trial performances were identified separately for each group using Student’s paired t-tests. All data were analyzed using SPSS version 14.0 for Windows, and statistical significance was set at P ≤ 0.05.

RESULTS

Anthropometric and physiological characteristics of both groups are shown in Table 1. The WA and AB athletes were matched successfully for age and body mass. However, anticipated differences (P < 0.05) in \( V\text{O}_2\text{peak} \), \( W\text{peak} \), and hence the corresponding 50% \( W\text{peak} \) between groups were identified.

Is There Agreement Between Intestinal and Intra-Aural Temperature in Spinal Cord-Injured Athletes During Intermittent Submaximal Exercise?

Body temperature, averaged over methods, trials, and time, was 37.2°C (95% CI = 37.0–37.4°C). Averaged over both trials and all exercise times, measurements of gastrointestinal temperature were significantly higher than those of Tad (mean difference = 0.6°C, 95% CI = 0.5–0.7°C, P < 0.0005) (Fig. 1, A and B). The magnitude of this difference between measurement methods did not depend on repeated trial (P = 0.74) or exercise time (P = 0.93). The random error (1.96 × SDiff, where SDiff is the standard deviation of paired differences) between methods amounted to ±0.9°C.

Fig. 1. Body temperature changes over time for gastric temperature [telemetry pill (Tpill)] and for auditory canal temperature (Tad) during session 1 (A) and session 2 (B).
Irrespective of measurement method ($P = 0.74$) or exercise time ($P > 0.99$), body temperature was generally higher in the second compared with the first repeated trial (mean difference = 0.3°C, 95% CI = 0.2 to 0.4°C, $P < 0.0005$). Examination of the Bland-Altman plots (Fig. 2, A and B) for these between-trial differences reveals that body temperature was particularly higher in the second trial for one subject (complete C7 lesion). The three-way interaction between factors was not statistically significant ($P > 0.99$), which suggests that the general increase in body temperature during the exercise protocol did not depend on measurement method or trial, despite the general systematic differences between these factors (Fig. 2C). The random error ($1.96 \times \text{SDiff}$) between repeated trials amounted to ±1.2°C and ±1.1°C for gastric and $T_{ac}$, respectively. The within-subjects SD was ~0.4°C for both measurement methods.

**Is HC Effective in Both Wheelchair and Able-Bodied Participants As a Method of Reducing Exercise-Induced Hyperthermia?**

Changes in $T_{ac}$ over the duration of the study between conditions and separately for the two groups are shown in Fig. 3. The $T_{ac}$ at 0, 60, and 70 min for WA and AB are shown in Table 3 for clarity. The first 60 min represents the steady-state exercise in the heat, whereas 60–70 min represents the 10-min intervention period. Nonsignificant condition × time interactions for both WA ($F_{15,75} = 1.5, P = 0.14$) and AB ($F_{15,90} = 1.2, P = 0.32$) confirmed that the exercise-induced changes in $T_{ac}$ were similar in each trial before the intervention (Table 3). However, the exercise-induced increase was evidently greater in AB compared with WA (2.0 vs. 1.3°C change, respectively). Significant condition × time interactions for both WA ($F_{9,45} = 3.1, P = 0.01$) and AB ($F_{9,54} = 10.0, P < 0.0005$) over the intervention period demonstrated that HC resulted in greater reductions in $T_{ac}$ compared with NC (Fig. 3 and Table 3). Simple-effects analyses suggested that the reductions in $T_{ac}$ were noteworthy after 4 min of HC in both groups. The AB experienced greater reductions in $T_{ac}$ compared with WA ($P < 0.05$) (Table 3). The difference in $\Delta T_{ac}$ after 10 min HC and NC is 0.2°C and 0.4°C (WA and AB, respectively); these small reductions should be seen as a useful benefit following only 10 min cooling.

Mean $T_{sk}$ increased to 34.9°C (SD 0.68) and 34.9°C (SD 0.74) for wheelchair participants, and 36.1°C (SD 0.6) and 36.6°C (SD 0.5) for the able-bodied participants (NC and HC, respectively). Following the NC trial, mean $T_{sk}$ reduced by 0.25°C (SD 0.63) and 0.49°C (SD 0.38), and mean $T_{sk}$ fell significantly more in HC compared with NC [1.12°C (SD 0.57) and 1.33°C (SD 0.5) ($P < 0.05$; WA and AB, respectively)]. Heart rate was significantly reduced after the 10-min recovery period with HC compared with NC for the AB [25 beats/min (SD 6) vs. 21 beats/min (SD 5); $P < 0.05$]; this trend was also apparent with the WA [22 beats/min (SD 11) vs. 19 beats/min (SD 10)]. There was also a slight reduction in thermal sensation following HC although this was nonsignificant.

**Is the Effectiveness of HC Dependent on the Initial Rise in Temperature, with Greater Elevation in Temperature Showing an Augmented Response?**

Figure 4 illustrates the relationship between the initial rise in $T_{ac}$ and the change in $T_{ac}$ following 10 min of HC. This relation for both groups suggested that the magnitude of cooling treatment effect was associated with higher final $T_{ac}$ value after 60 min of exercise ($r = -0.78, P < 0.05$, and $r = -0.86, P = 0.013$, for the WA and AB, respectively).

**Does HC Improve Subsequent Endurance Performance?**

The mean AB 3-km time trial of 281 s (SD 25) without cooling fell by 14 s to 267 s (SD 17) following the HC intervention ($P \geq 0.025$). The WA group reduced their time to complete 1-km by 20.5 s (SD 24.2) [4.6% (SD)] after HC but did not show a significant difference in times between trials ($P \geq 0.083$). This was due to the large SD values and...
variability in individual response and fitness. Groups were not directly compared due to different distances covered, but both groups showed similar percent change in response to HC, highlighting that HC could improve their time trial performance.

DISCUSSION

The main experiment was prefaced with the first detailed measurement check on the use of Tac in WA during exercise. The findings from this part of our research work suggested that the exercise-mediated increase in body temperature was similar in magnitude between temperature measurement methods and also repeated trials. Nevertheless, there were general systematic differences between methods in terms of absolute temperature, a finding that has been reported before for AB athletes (12). Inspection of individual data suggested that agreement between trials was worse for those individuals with a high lesion level. Therefore, we excluded the quadriplegic participants in the main experiment.

HC Will Be an Effective Method of Reducing Exercise-Induced Hyperthermia for Both Wheelchair and Able-Bodied Athletes

The primary finding of this investigation was that HC significantly lowered Tac in both the WA and AB participants. HC effectively lowered Tac in the AB within 10 min, supporting the mechanism in hyperthermic individuals, which is supportive of previous work (10, 14, 15, 18). It can be postulated that the arteriovenous anastomoses (AVAs) remained dilated, and cooled blood in the hands flowed directly to the body’s core via the superficial veins to lower heat strain (14, 17). When normothermic individuals immerse hands in cold water, peripheral vasoconstriction closes the AVAs to prevent heat loss as a survival mechanism (14). In these cases cooler blood is shunted to the deeper veins to be heated by warm arterial blood, therefore protecting the core from extreme changes in temperature; this has been referred to as countercurrent heat exchange (17). The more gradual reduction in Tac demonstrated by most of the WA group may suggest countercurrent heat exchange occurred. The core temperature was lowered much slower due to restricted peripheral blood flow and redirection of blood to deeper vascular structures. As the results demonstrated, the WA did not show large elevations in Tac and therefore would support House et al. (14), who stated HC is self-limiting in which the peripheral blood flow controls the amount of cooling dependent on core temperature.

HC did lower mean Tsk (17), and there was a tendency for ratings of thermal sensation to be reduced. The latter could lower the psychological stresses of exercising in the heat. HC lowered HR values over the 10-min rest, highlighting the fact

Table 3. Insulated auditory canal temperature measured at 0 min (preexercise), 60 min (end exercise), and 70 min (postintervention)

<table>
<thead>
<tr>
<th>Group and Condition</th>
<th>0 min</th>
<th>60 min</th>
<th>70 min</th>
<th>Δ 0 to 60 min (Exercise)</th>
<th>Δ 60 to 70 min (Intervention)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA and HC</td>
<td>36.4 (0.3)</td>
<td>37.6 (0.6)</td>
<td>37.2 (0.4)</td>
<td>1.3 (0.4)</td>
<td>-0.4 (0.4)</td>
</tr>
<tr>
<td>WA and NC</td>
<td>36.5 (0.4)</td>
<td>37.7 (0.7)</td>
<td>37.5 (0.6)</td>
<td>1.3 (0.4)</td>
<td>-0.2 (0.1)</td>
</tr>
<tr>
<td>AB and HC</td>
<td>36.6 (0.2)</td>
<td>38.7 (0.3)</td>
<td>37.5 (0.2)</td>
<td>2.0 (0.4)</td>
<td>1.2 (0.2)</td>
</tr>
<tr>
<td>AB and NC</td>
<td>36.6 (0.2)</td>
<td>38.7 (0.3)</td>
<td>37.9 (0.3)</td>
<td>2.0 (0.3)</td>
<td>-0.8 (0.2)</td>
</tr>
</tbody>
</table>

All values are means (SD). HC, hand cooling; NC, no cooling; Tac, insulated auditory canal temperature. Delta (Δ) values are changes in Tac from 0 to 60 min and from 60 to 70 min.
that HC for wheelchair participants could be used as an intermittent recovery aid, yet may not be appropriate for precooling. Precooling techniques have been shown to have endurance performance effects in able-bodied athletes (10, 15); we have shown that HC is effective in much shorter distances (3 km). The fact that this was not seen in WA could be due to a combination of the slightly smaller sample and the diverse nature of the disability levels, causing a large variability in this group. Moreover, it could be suggested that the impact on performance may be due to insufficient heating in the first instance to benefit from cooling, and only vasoconstriction occurred during HC. It should be noted that none of these athletes particularly enjoyed HC, predominantly those with higher lesion levels. Feelings of numbness, lack of grip, and susceptibility to blister were experienced, which may ultimately suggest that HC is not practical for sports where hand dexterity is important. Only one of the AB athletes described similar feelings; otherwise they all found it refreshing and noted its beneficial effect.

**Effectiveness of HC Will Be Dependent on the Initial Rise in Temperature, with Greater Elevation in Temperature Showing an Augmented Response**

The effectiveness of HC appeared to be related to the $T_{ac}$ value from which the HC commenced, which is evident in the more favorable responses in the AB athletes. From an individual perspective, two WA with the highest final $T_{ac}$ values (one with the greatest loss of evaporative cooling mechanisms, and one with the greatest functional capacity) both demonstrated a more pronounced cooling effect. This supports Hagobian et al. (11), who suggested higher core temperatures and larger delta changes can increase the efficacy of a cooling strategy, hence the success of their foot cooling device in spinal cord-injured persons.

**Methodological Considerations**

In the present study we controlled the exercise intensity to 50% $W_{peak}$ for wheelchair and cycling exercise, which was successful in terms of its specificity to athletic group and the repeatability found in $T_{ac}$ over the 60-min protocol between NC and HC trials. Yet as a result of this experimental design, it was clearly evident that different absolute workloads existed between the groups due to the differences in exercise modality. Consequently, the difference in $T_{ac}$ between groups could be attributed to the smaller muscle mass that was used during wheelchair propulsion compared with cycling. Future work should use 70% $W_{peak}$ for the wheelchair participants to see a greater rise in $T_{ac}$, which may then show a greater impact of HC on reducing $T_{ac}$ and improving subsequent 1-km performance.

It is also important to note that we used $T_{ac}$ as a surrogate of core temperature for the main experimental aspects of examining HC. It appears that the precision of its use compared with the gastrointestinal temperature is dependent on the disability of the wheelchair participant, hence the exclusion of wheelchair participants for selective components of the studies outlined above. It is, however, important to note that the exploratory data collected in wheelchair participants would suggest that the small amount of random measurement error and similar thermal responses to exercise suggests that $T_{ac}$ is an appropriate measure to use.

**Conclusion**

The main finding from this investigation suggests HC will provide an effective way to increase the reduction of $T_{ac}$ during recovery after prolonged exercise in the heat in both wheelchair and able-bodied participants. HC had an impact on significantly improving 3-km performance in the AB athletes and trends toward positive gains for the 1-km performance times of the WA group. The drop in $T_{ac}$ was greater due to HC when $T_{ac}$ started at a greater value. Thus the choice of cooling method should be specific to the individual response and level of disability.

**ACKNOWLEDGMENTS**

We thank all the athletes for participation in this investigation and the support provided by the British Tennis Federation. We also acknowledge the initial guidance from Dr Jim House and Dr Mike Price and thank John Lenton and Helen Alfano for help during the testing sessions.

**GRANTS**

This study was made possible by the loan of the data logger from the British Olympic Medical Institute and sponsorship from Cranlea by assisting with the purchase of the telemetry pills, which were awarded through a British Association of Sport and Exercise Sciences Scientific Award.

**REFERENCES**


