Fluid Intake During Wheelchair Exercise in the Heat: Effects of Localized Cooling Garments

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Background: Wheelchair tennis players, competing in hot and humid environments, are faced with an increased risk of heat-related illness and impaired performance. This study examined the effects of head and neck cooling garments on perceptions of exertion (RPE), thermal sensation (TS), and water consumption during wheelchair exercise at 30.4 ± 0.6°C. Methods: Eight highly trained wheelchair tennis players (1 amputee and 7 spinal cord injured) completed two 60-min, intermittent sprint trials; once with cooling (COOL) and once without cooling (CON) in a balanced cross-over design. Players could drink water ad libitum at five predetermined intervals during each trial. Heart rate, blood lactate concentration, peak speed, TS, and RPE were recorded during the trials. Body mass and water consumption were measured before and after each trial. Results: Water consumption was lower in COOL compared with CON (700 ± 393 mL vs. 1198 ± 675 mL respectively; P = 0.042). Trends in data suggested lower RPE and TS under COOL conditions (N.S.). Total sweat losses ranged from 200 to 1300 mL; this equated to ~1% dehydration after water consumption had been accounted for when averaged across all trials. The ad libitum drinking volumes matched and, in some cases, were greater than the total sweat losses. Conclusions: These results suggest that there is a counterproductive effect of head and neck cooling garments on water consumption. However, despite consuming volumes of water at least equivalent to total sweat loss, changes in body mass suggest an incidence of mild dehydration during wheelchair tennis in the heat.

Keywords: thermoregulation, wheelchair propulsion, spinal cord injury, wheelchair tennis, paralympic athletes

Wheelchair tennis has rapidly become one of the UK’s highest profile wheelchair sports, with two Paralympic medals being won in the quadriplegic events by British athletes at the 2004 Paralympic Games in Athens. Wheelchair tennis is characterized by an intermittent activity profile with two to three explosive efforts of pushing the wheelchair superimposed on a background of aerobic activity. The gold medal matches in Athens for both males and females took more than 1 hour to complete. Furthermore, in the preliminarily rounds it was not uncommon to see play last up to 2 hours in hot and humid climates. Surprisingly, given it has long been known that individuals with a spinal cord injury (SCI) are less-effective thermoregulators than able-bodied in hot environments, little information is available on the thermoregulatory responses during wheelchair propulsion in the heat. Additionally, to our knowledge there are no published data which would allow coaches to fully understand the hydration strategies needed for wheelchair tennis players to tolerate intermittent sprint activity (ISA) for long durations in hot climates.

Paramount to the wheelchair tennis player is guidance on exercise in the heat using well-established methods for improving performance through structured heat acclimatization, fluid intake, and cooling interventions. Thus far, no research has investigated the influence of structured training sessions in the heat in groups of wheelchair athletes. In terms of fluid intake, exercise performance can be impaired by 20% to 30% if dehydrated by as little as 2% of body weight in able-bodied athletes. Moreover, there is evidence to suggest that when dehydrated, mental function, decision making, and reaction response times, which are all vital to success in tennis, could also become affected. Fluid intake guidance for able-bodied athletes is based on the fact that fluids should be replaced during exercise preferably at a rate equal to sweat rate, and that it is important not to over-consume fluids as this may potentially cause hyponatremia. This guidance on fluid replacement is difficult to determine for wheelchair tennis players, where the individual’s on-court fluid loss will depend not only on the environmental conditions but also the level of SCI and limited sweating capacity. The sparse data involving SCI athletes has indicated that cooling interventions may help reduce thermal and cardiovascular strain, in turn reducing perceptual responses, and contributing toward improved exercise tolerance. If this message is being endorsed by the British Paralympic Association, then it is important to determine whether cooling interventions have an impact on the voluntary drinking habits of our athletes. Indeed, it has been noted that cooling interventions relieve the feelings of thermal discomfort and thirst and provide a general perception that the exercise load is easier. Accordingly, the purpose of this study was to examine the effects of head and neck cooling on perceptions of exertion, thermal sensation, and fluid intake while performing high-intensity, intermittent wheelchair activity, in a hot environment.

**Methods**

**Participants**

Eight highly trained wheelchair tennis players (5 male and 3 female) volunteered to participate in the study. Participants were between the ages of 24 and 44 years with a mean (±SD) body mass of 66.7 ± 17.3 kg with disabilities which included 1 athlete with a single leg amputation and 7 athletes with a spinal cord injury.
(Table 1). They were considered as highly trained, having competed regularly at an international level and being part of the Great Britain squad in preparation for Athens 2004. All participants provided written informed consent before any involvement in the study. Approval for the study procedures was obtained from the University Research Ethics Committee. All participants were tested in their sports-specific wheelchairs on the same wheelchair ergometer (WERG; Bromakin, Loughborough, UK). The participants attended the laboratory on a regular basis, and their testing/screening involved using this WERG. Participants were, therefore, familiar with the testing procedures used in this study. The WERG consisted of a single cylinder (length, 1.14 m; circumference, 0.48 m) with a flywheel sensor connected to the roller and interfaced to a laptop computer which calculated and displayed the wheelchair velocity.

**Peak Oxygen Uptake.** An incremental speed test was used to determine peak oxygen uptake (VO$_{2peak}$) as described previously.$^{10,11}$ Heart rate (HR) was monitored continuously using radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland). Expired air samples were collected and analyzed using the Douglas bag technique over the last two consecutive stages of the test. The concentration of oxygen and carbon dioxide in the expired air samples was determined using a paramagnetic oxygen analyzer (Series 1400, Servomex Ltd., Sussex, UK) and an infrared carbon dioxide analyzer (Series 1400, Servomex Ltd., Sussex, UK). Expired air volumes were measured using a dry gas meter (Harvard Apparatus, Kent, UK) and corrected to standard temperature and pressure (dry). Oxygen uptake (VO$_2$), carbon dioxide output (VO$_2$), expired minute ventilation (V$_E$), and respiratory exchange ratio (RER) were calculated for each Douglas bag. The analyzers were calibrated with gases of known concentration before each test and the linearity of the gas meter was checked using a 3-L calibration syringe.

**Table 1** Disability, Physical Characteristics, and Aerobic Capacity of the Wheelchair Tennis Players

<table>
<thead>
<tr>
<th>Participant</th>
<th>Level of Injury</th>
<th>Gender</th>
<th>Age (y)</th>
<th>Body mass (kg)</th>
<th>Years playing tennis</th>
<th>Peak aerobic capacity (L·min$^{-1}$)</th>
<th>HR$_{peak}$ (beats·min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C6-C7</td>
<td>M</td>
<td>34.4</td>
<td>78.1</td>
<td>8</td>
<td>1.21</td>
<td>117</td>
</tr>
<tr>
<td>2</td>
<td>C7*</td>
<td>M</td>
<td>35.5</td>
<td>95.9</td>
<td>8</td>
<td>1.71</td>
<td>139</td>
</tr>
<tr>
<td>3</td>
<td>T3-4</td>
<td>F</td>
<td>31.9</td>
<td>62.1</td>
<td>8</td>
<td>1.65</td>
<td>156</td>
</tr>
<tr>
<td>4</td>
<td>T10</td>
<td>M</td>
<td>31.9</td>
<td>59.0</td>
<td>6</td>
<td>2.10</td>
<td>196</td>
</tr>
<tr>
<td>5</td>
<td>T10*</td>
<td>F</td>
<td>23.5</td>
<td>43.0</td>
<td>14</td>
<td>1.10</td>
<td>192</td>
</tr>
<tr>
<td>6</td>
<td>T6</td>
<td>M</td>
<td>43.7</td>
<td>75.6</td>
<td>10</td>
<td>1.47</td>
<td>154</td>
</tr>
<tr>
<td>7</td>
<td>L1*</td>
<td>F</td>
<td>34.9</td>
<td>47.6</td>
<td>8</td>
<td>1.98</td>
<td>179</td>
</tr>
<tr>
<td>8</td>
<td>AMP</td>
<td>M</td>
<td>24.2</td>
<td>72.1</td>
<td>7</td>
<td>2.82</td>
<td>197</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>—</td>
<td>32.5</td>
<td>66.7</td>
<td>8.6</td>
<td>1.76</td>
<td>166</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td></td>
<td>6.5</td>
<td>17.3</td>
<td>2.4</td>
<td>0.55</td>
<td>30</td>
</tr>
</tbody>
</table>

*Incomplete spinal cord lesion.
Experimental Conditions

Wheelchair propulsion was performed in an environmental chamber maintained at 30.4 ± 0.6°C and 54.0 ± 3.8% relative humidity. Temperature selection was chosen to replicate the conditions that the wheelchair tennis players encountered at the 2004 Paralympic Games. Each participant completed the same 60-minute ISA at the same time of day on 2 occasions, separated by 7 to 10 days in a counter-balanced order. The condition of exercise cooling (COOL) was achieved by a commercial cooling hat (Blu Bandoo, USA) and neckband (Frio Cooling Products, Haverfordwest, UK) containing water absorbing crystals. The hat and neckband were refreshed every 10 minutes, during the 2-minute recovery periods. The second condition was performed with no cooling intervention (CON), conditions were presented to the participants in a counter-balanced order and the subjects served as their own controls.

Resting Measurements

Participants were instructed to arrive at the laboratory in a hydrated state, to refrain from alcohol, caffeine, and strenuous physical activity and to follow the same dietary, fluid, and activity routine for the 24 hours before both trials. Before all testing protocols, subjects provided a waking urine sample for the assessment of hydration status via urine specific gravity. Nude body mass was calculated to the nearest 0.1 kg using a seated balance scale (Seca 710, seated scales, Hamburg, Germany) after individuals had voided the bladder. Capillary blood samples were taken from the ear lobe to measure resting blood lactate [La]b concentration (YSI 1500 Sport; Yellow Springs), hemoglobin (Clandon HemoCue, HemoCue Ltd., Sheffield, England), and hematocrit (Microcentrifuge, Hawksley hematocrit reader). The average of 3 readings was used for hematocrit analysis. Drinking bottles containing water standardized to an initial 18°C, which were taken inside the heat chamber during the exercise period, were weighed at the beginning of each exercise session using a Top pan balance (Oertling 21TD, L Oertling Ltd, London, UK).

Participants undertook a standardized 5-minute warm-up, followed by 3 maximum effort sprints of 5 seconds in duration, to determine peak speed (PS). The PS recorded on the first visit was used for the subsequent visit. The 60-minute ISA incorporated 3 movement categories specific to wheelchair tennis, passive recovery, sprinting from a stationary position, and submaximal pushing. It consisted of 10-minute blocks of ISA followed by 2 minutes of passive recovery, repeated 5 times, which is shown in Figure 1. During the rest periods, participants were free to take on fluids ad libitum and the amount consumed was recorded as the fluid intake and used to calculate sweat loss. Fluid was restricted to water only. To avoid bias, the specific purpose relating to drinking behavior was not disclosed.

Measurements

During each trial PS was recorded for each 5-second sprint and HR was measured continuously via short range telemetry (Accurex Plus, Polar Electro Oy, Kempele, Finland). Rating of perceived exertion (RPE; Borg scale) was recorded every 2 minutes. A rating of perceived thermal sensation (TS) was also measured every 2 minutes through a subjective rating scale, with categories ranging from 0.0 (“unbearably cold”) to 8.0 (“unbearably hot”) in 0.5-unit increments. Upon
completion of each 10-minute block of pushing, a capillary blood sample was collected from the ear lobe and analyzed for \([\text{La}]_b\) concentration.

Upon completion of the exercise protocol participants exited the environmental chamber and posttest body mass was recorded after toweling off any perspiration. Sweat loss was calculated from the change in body weight plus total water intake.

**Figure 1** — Diagrammatic representation of the intermittent sprint activity showing 2 of the 5 sets (top) and the breakdown of each set into 2-minute blocks of 10 seconds of rest, 5 seconds of maximum effort sprint, and 105 seconds of pushing at 50% peak speed (bottom).
Total fluid loss was calculated as sweat loss minus water intake and was expressed as a percentage of initial body weight. Whole-body sweat loss was calculated from the change in nude body mass during exercise after correction for water ingestion. The percent changes in plasma volume were calculated by using hematocrit and hemoglobin from capillary blood samples obtained following the exercise session. Plasma volume change was estimated from the methods described by Dill and Costill and Hill.

**Statistical Analyses**

The Statistics Package for the Social Sciences (SPSS, Chicago, IL) was used for all statistical analyses. Between-condition differences in change (Δ) in plasma volume, mean water consumption, Δ in body mass, and sweat loss were also analyzed using paired Student’s t tests. A two-way analysis of variance with repeated measurements of condition and time was applied to HR, TS, RPE, and [La]b concentration. A Bonferroni post hoc test was applied to determine the location of any significant main effects. The relationship between the volume of sweat loss and the volume of drink consumed during the ISA in the heat, with and without cooling aids, was examined using Pearson’s product moment correlation. Significance was set at $P \leq 0.05$.

**Results**

The disability and selected characteristics of the tennis players are presented in Table 1. Mean VO$_{2\text{peak}}$ was $1.76 \pm 0.55$ L·min$^{-1}$ with a HR$_{\text{peak}}$ of $166 \pm 30$ beats·min$^{-1}$ for the group, this was highly variable, given the disability levels ranged from C6-7 through to amputation. Currently, wheelchair tennis competition rules stipulate that participants 1 and 2 would compete in the quadriplegic class while participants 3 to 8 would compete together in the open class. To control for the variance in disability level, yet remain with a sport-specific sample, the experimental design consisted of a repeated measures design where subjects served as their own controls.

Following the 60 minutes of ISA wheelchair propulsion, mean HR was elevated to $139 \pm 20$ beats·min$^{-1}$ and $136 \pm 20$ beats·min$^{-1}$ with [La]$_b$ concentration values approaching 3 mmol·L$^{-1}$ for both CON and COOL, respectively (Table 2). The intensity of effort based upon the percentage of HR$_{\text{peak}}$ was of a moderate to high nature (ranging from 64% to 86%). There were no differences in these physiological variables between the two trials (N.S.), indicating that the localized cooling garments to the head had no effect on performance.

The effect of the cooling garments on sweating and fluid balance is shown in Table 3. The changes in plasma volume during both the COOL and CON trials were similar ($5.3 \pm 9.8\%$ and $4.2 \pm 8.8\%$, respectively). However, the players consumed 42% less water, on average during COOL ($700 \pm 393$ mL) than CON ($1198 \pm 657$ mL), $P = .042$. Interestingly, hydration status of the players appears to have been maintained during exercise in the COOL condition as there was no change in body mass (BM) after the exercise (pre- and postexercise BM of 66.7 kg). However, during the CON condition, due to the greater intake of fluids there was a $+0.8 \pm 0.6\%$ change in BM (pre- and postexercise BM of 66.5 and 67.1 kg, respectively). Despite the noted differences in fluid consumption, mean sweat
volume lost between the two conditions (CON and COOL) was not significantly different (687 ± 350 and 654 ± 357 mL·h⁻¹, respectively). Under both conditions, the sweat volume lost ranged from 300 to 1900 mL during the ISA. There was no relationship (P = 0.147) between the sweat volume lost and drink volume consumed during the COOL condition, yet a relationship existed (P = 0.002) during the CON condition (Figure 2). This relationship may have been driven by the ratings of thermal sensation (TS) across the 5 sets of exercise which can be seen in Figure 3. Despite a tendency for the TS and RPE to be lower during the COOL condition, use of the cooling head and neck garments did not influence these perceptions significantly (Table 2; P > 0.05).

From a practical perspective, if no water had been consumed during the 60-minute exercise duration then the change in BM during COOL was −1.1 ± 0.8% and −1.0 ± 0.6% during CON (N.S.). In addition, as a result of the exercise in the heat one player would have reached a dehydration level of over a 2% of their initial body mass.

### Discussion

The wheelchair tennis players who took part in this study were all members of the Great Britain national team, currently participating in their summer competitive tennis circuit. The mean VO₂peak of 1.76 ± 0.55 L·min⁻¹ (1.85 ± 0.55 L·min⁻¹ excluding the participants with cervical lesions) are similar to those reported for other wheelchair tennis players, yet slightly lower than the endurance base characterized by wheelchair racers in the UK. In summary, this study found that the wheelchair tennis players varied greatly in their sweating responses and drinking behaviors.
Table 3  Pre-exercise and Postexercise Body Mass, Fluid Intake, and Calculated Fluid Loss During the Exercise Period of Both Conditions

<table>
<thead>
<tr>
<th>Trial</th>
<th>Pre BM (kg)</th>
<th>Post BM (kg)</th>
<th>Fluid intake (mL)</th>
<th>Sweat rate (mL)</th>
<th>Actual change in BM (with fluids) (%)</th>
<th>Whole-body sweat loss (assuming no fluids were taken) (%)</th>
<th>Fluid recommendations mL·h⁻¹ per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOL</td>
<td>66.7 (17.3)</td>
<td>66.7 (17.4)</td>
<td>700 (393)</td>
<td>687 (409)</td>
<td>0.0 (0.6)</td>
<td>−1.1 (0.75)</td>
<td>1030 (614)</td>
</tr>
<tr>
<td>range</td>
<td>43.0 to 95.9</td>
<td>43.2 to 95.7</td>
<td>300 to 1500</td>
<td>200 to 1300</td>
<td>−0.8 to 0.7</td>
<td>−2.7 to −0.3</td>
<td>400 to 2000</td>
</tr>
<tr>
<td>CON</td>
<td>66.5 (17.3)</td>
<td>67.1 (17.4)</td>
<td>1198 (657)*</td>
<td>648 (360)</td>
<td>0.8 (0.6)*</td>
<td>−1.0 (0.63)</td>
<td>973 (540)</td>
</tr>
<tr>
<td>range</td>
<td>43.3 to 96.4</td>
<td>43.7 to 97.2</td>
<td>500 to 1900</td>
<td>200 to 1100</td>
<td>−0.2 to 1.9</td>
<td>−2.2 to −0.3</td>
<td>300 to 1700</td>
</tr>
</tbody>
</table>

Values are means (± SD) for each trial. *Based upon the calculation of sweat rate * 1.5.
Figure 2 — The relationship between the volume of sweat loss and the fluid consumed during the ISA 60 minutes in the heat during (a) the COOL condition ($r = 0.56; \text{N.S.}$) and (b) without cooling aids (CON) ($r = 0.90; P = 0.002$).

Figure 3 — Thermal sensation after each 10-minute block, during the 60-minute ISA. $P < 0.05$ across time and N.S. between groups.
were influenced by wearing head and neck cooling garments, as the self-selected fluid intakes were significantly reduced \((P = 0.042)\) in the COOL condition.

Although limited tennis research has focused on the wheelchair game, the fact that individuals with spinal cord lesions exhibit a reduced whole-body sweating capacity\(^2\) may explain the fact that they maintained a good fluid balance. However, regardless of disability, the need for individualized fluid strategies is an important consideration. This is a prominent message in the literature, where the fluid strategies have been examined in tennis players, with sweat rates of >2500 mL·h\(^{-1}\) playing in a warm environment.\(^3\) Interestingly, in the current study all players experienced an increase in body mass over the ISA which is contrary to the majority of literature within able-bodied athletes when performing exercise in the heat with no fluid intake restrictions.\(^{19, 20–21}\) Therefore, all players had successfully replaced their fluid losses, and were not in any state of dehydration.\(^22\) However, on an individual basis, one player, when corrected for fluid intake would have become dehydrated by over 2\% (2.7\% and 2.2\% COOL and CON, respectively), which may have had a major influence on match play performance in terms of decision making and fatigue.\(^4–7, 22\) Yet this participant recognized the importance of maintaining hydration status and did in fact consume fluids at a rate of 1300 mL·h\(^{-1}\). It is, however, unknown whether this fluid replacement rate would have continued beyond 60 minutes of exercise. Moreover, although this individual is now aware of their high sweat rate, there may be barriers during game play, such as the rules of the game and timing of breaks and play duration to fully implement a fluid strategy to offset dehydration.\(^23\)

Other than the lower sweat rates, the two quadriplegics responded similarly to the exercise when compared with the other athletes. There were no differences in the perceptual responses found in overall effort or TS, these data were within two standard deviations of the group mean and therefore, included. It seems likely that the localized cooling garments were sufficient for players to augment feelings of reduced heat stress (TS) when compared with the CON condition. In turn, it is speculated that these subjective ratings influenced water ingestion, as during the COOL condition players drank significantly less fluid \((P = 0.042)\). Even though the sweat rates did not differ between conditions, it was likely that the slightly elevated feelings of heat stress resulted in a better relationship between the sweat loss and fluid intakes \((r = 0.90; P = .002)\) during the CON condition. On the other hand in line with previous able-bodied work,\(^19\) it is likely that the poor relationship between sweat loss and fluids when cooling garments were worn \((r = 0.56; \text{N.S.})\) is related to 3 of the 8 participants underestimating their fluid balance.

The cooling garments used in the current study were similar to the refrigerated head piece examined as a cooling aid in wheelchair athletes previously.\(^23\) The most notable fact from the work of Armstrong and colleagues\(^24\) was that the head cooling garments did not prevent increased heat storage and that cooling garments such as ice-packed vests are required for greater cooling power.\(^8, 24\) Practical considerations influence the development of cooling strategies for competitive athletes. Whether the strategy can be implemented within the laws that govern the sport, without adversely influencing the playing rhythm, is a challenge for the sports physiologist. Interestingly, it is evident that many wheelchair tennis players elect to wear cooling garments around the head in the form of wet towels in between sets. The importance of feeling cooler in this sample should not be underestimated, as a tennis match may be lost through both fatigue and loss in concentration.\(^22\) What is pertinent in
the present sample is that those players that cannot accurately assess their thermal status may be at risk for developing a heat-related illness if they feel cooler while their core temperature is still rising.\textsuperscript{7} Despite the fact that fluid intakes were matched after 60 minutes, it is important to note that the experimental protocol allowed the players to drink on 5 occasions. Thus, longer match play situations may place the player at risk if no fluids are permitted.\textsuperscript{25}

It was our intention to select players from the pool of athletes involved during the preparations for Athens 2004 Paralympics. Indeed, the employment of only 8 may be considered low. From a practical perspective it should be noted that a number of trends have emerged with the perceptual ratings (RPE and TS). Although not statistically significant, the positive trend suggests some potential benefit of cooling aids, without any detrimental effect on pre- and postexercise body mass over 60 minutes. That the players consumed 42\% less water during COOL is a possible concern should this be a direct result of the cooling strategy adopted during this condition, particularly during longer match play conditions. While most players did make a genuine effort to stay well hydrated to maintain performance, this study did not address the sweat content and whether there was an electrolyte deficit. The combined effects of dehydration and electrolyte losses have been evident in able-bodied tennis players experiencing heat cramp.\textsuperscript{25} Hence, future topics of interest within this population would be to explore both the fluid intake preferences and effects of electrolyte beverages on fluid intake and thermal strain in a comparative manner to previous work.\textsuperscript{17,26}

In conclusion, the results of this study do not support the use of localized head and neck cooling in wheelchair tennis players unless they are able to adapt their fluid intake strategy accordingly.

Acknowledgments

We thank all the athletes for their participation in this investigation. We are grateful to John Lenton for helping with the wheelchair ergometer set-up, Katie Pickering and Carole Jepson for assistance during the data collection. This investigation was supported by a grant for applied physiological support from the British Tennis Foundation.

References