

1 Thermoregulatory Responses during Competitive Wheelchair Rugby Match

2 Play

3 Abstract

4 The purpose of this study was to determine whether a player's physical impairment
5 or activity profile was related to the amount of thermal strain experienced during
6 wheelchair rugby match play. Seventeen elite wheelchair rugby players played a
7 competitive match, whilst activity profiles, measures of core and skin temperature,
8 heart rate and perceptual responses were taken. Players were divided into two groups
9 depending on their physical impairment; players with a cervical spinal cord injury, (n
10 = 10) or non-spinal related physical impairment (n = 7). Total distance was lower
11 (4842 ± 324 m vs. 5541 ± 316 m, $p < 0.01$, ES = 2.2) and mean speed slower ($1.13 \pm$
12 0.11 m·s⁻¹ vs 1.27 ± 0.11 m·s⁻¹, $p < 0.03$, ES = 1.3) in players with a spinal cord
13 injury. Yet, the change in core temperature ($1.6 \pm 0.4^{\circ}\text{C}$ vs. $0.7 \pm 0.3^{\circ}\text{C}$, $p < 0.01$, ES
14 = 2.5) was significantly greater in players with a spinal cord injury. In conclusion,
15 players with a spinal cord injury were under greater thermal strain during wheelchair
16 rugby match play, as a result of their reduced heat loss capacity, due to their physical
17 impairment and not because of their activity profile.

18 **Keywords:** Thermoregulation, Spinal cord injury, Tetraplegia, Paralympic sport

19

20 **Introduction**

21 Wheelchair rugby (WCR) was originally developed for individuals with tetraplegia
22 (spinal cord injury (SCI) at the cervical region of the spinal cord). However, recent
23 changes to the International Wheelchair Rugby Federation (IWRF) classification
24 system have meant that individuals with other physical impairments, such as cerebral
25 palsy, multiple amputations and neuromuscular disease, are now eligible to compete.
26 Based on physical impairment, male and female WCR players whom compete
27 together are classified into 1 of 8 classification groups from 0.5 (most impaired) to
28 3.5 (least impaired, International Wheelchair Rugby Federation, International Rules
29 for the Sport of Wheelchair Rugby June (2013). In Internet:
30 [http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf)
31 [2015_English.pdf](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf); (10th November 2015)). In individuals with a SCI, in addition to
32 the lack of voluntary control of their torso and upper limb dysfunction, they are also
33 thermoregulatory impaired [14] proportional to their lesion level [26]. Their
34 thermoregulatory impairment is due to a lack of central sudomotor and vasomotor
35 control below their lesion level [8, 17, 23]. For example, it has previously been
36 shown that athletes with tetraplegia exhibit greater thermal strain than athletes with
37 paraplegia (thoracic, lumbar, or sacral SCI) during intermittent wheelchair exercise
38 in ~20°C [13]. Hence, players with tetraplegia within the same classification group
39 as players with a non-spinal related physical impairment (NON-SCI) may be at a
40 thermoregulatory disadvantage during WCR match play.

41 Studies have shown IWRF classification to be closely related to the volume of
42 activity elicited over a typical WCR quarter [31, 32, 34]. For example, high point
43 players (2.0-3.5 points) are capable of greater peak speeds and spend less time within

44 low speed zones compared to low point players (0.5-1.5 points) [31]. Furthermore,
45 high point players are shown to have better ball-handling skills, such as interceptions
46 and passes made and caught [21, 22], most likely attributed to these players
47 occupying offensive rather than defensive roles [31]. Interestingly, despite the noted
48 thermoregulatory impairment of individuals with tetraplegia, no study to date has
49 examined the combination of thermal strain of WCR players during match play and
50 the associated activity profiles. Individual thermoregulatory outcomes during
51 exercise may be influenced by independent factors, such as the physical attributes of
52 body mass and body composition [16]. Although, it has also been suggested that a
53 smaller percentage of individual variability in thermoregulatory responses is
54 explained by body composition in the able-bodied [5], due to the atrophy of skeletal
55 muscle in the lower limbs, whether the same variability exists for individuals with a
56 SCI is currently unknown.

57

58 Whether a player's physical impairment, activity profile or physical attributes
59 predisposes them to a greater amount of thermal strain during match play has both a
60 practical and clinical importance. For instance, identifying players under greater
61 thermal strain could enable both the implementation of targeted cooling strategies
62 and a reduction in performance decrements due to a high core temperature.
63 Furthermore, by investigating players during actual match play a physical challenge
64 and psychological stress is attained that is difficult to replicate in a laboratory. Thus
65 the purpose of this study was twofold 1) to compare the thermoregulatory responses
66 and activity profiles of players with a SCI to those players with a NON-SCI during
67 competitive WCR and 2) in those players with a SCI determine whether their
68 classification, activity profile and/or physical attributes were related to the thermal

69 strain experienced during competitive WCR. It was hypothesized that 1) players
70 with a SCI would be under a greater amount of thermal strain than players with a
71 NON-SCI during competitive WCR and 2) due to the greater activity levels of high
72 point players reported previously [31], high point players with a SCI would
73 experience a heightened thermal response.

74

75 **Methods**

76 *Participants:* Sixteen male and one female WCR player from the BT Great Britain
77 Wheelchair Rugby (GBWR) squad gave their written informed consent to participate
78 in this study in accordance with the Declaration of Helsinki and in line with the
79 ethical standards of the journal [15]. The study was approved by the University
80 Research Ethics Committee. Participants were divided into two groups, SCI (n = 10)
81 or NON-SCI (n = 7, Table 1).

82 *Experimental design:* All participants completed an incremental exercise test to
83 exhaustion on a treadmill for determination of peak oxygen uptake ($\dot{V}O_{2peak}$). On
84 separate occasions participants played in a WCR game at the squad's usual training
85 venue and in SCI, seven participants had a dual-energy X-ray absorptiometry (DXA)
86 scan. Three SCI participants, had a history of high levels of ionising radiation in the
87 previous 12 months and were excluded from having a DXA scan.

88 *Laboratory testing*

89 *Peak oxygen uptake ($\dot{V}O_{2peak}$).* The incremental exercise test was completed on a
90 motorised treadmill (HP Cosmos, Traunstein, Germany) at a constant 1.0 % gradient
91 as previously described [19]. In brief, the speed was continually increased by 0.2-0.4
92 $m \cdot s^{-1}$ every 3 min, dependent on the participant's level of impairment. A slower

93 starting speed and smaller speed increments were adopted for SCI players with
94 higher lesion levels (e.g. C5/6) and lower point players (e.g. 1.5) for NON-SCI. The
95 test was terminated when participants were unable to maintain the speed of the
96 treadmill.

97 *Body composition.* Skinfold measurements (Harpden Skinfold Callipers, Baly
98 International, West Sussex, UK) were taken for all participants (n = 17) in a seated
99 position from the biceps, triceps, subscapular and suprailliac to calculate the sum of
100 skinfolds (mm). However, to get a true reflection of body composition for
101 individuals with an SCI, according to recent studies, [12] a DXA scan was
102 performed for seven of SCI using a Lunar Prodigy Advance DXA scanner (GE
103 Lunar, Madison, WI, USA) following procedures previously described
104 [18]. The compartments measured were total body fat and lean tissue mass. Total
105 body fat and lean tissue mass percentage was obtained from the total body fat mass
106 and lean tissue mass, respectively, divided by the total body mass. Body surface area
107 (m^2) was estimated by the Dubois formula [6].

108 *Field testing*

109 *Match play.* Participants were separated into teams in consultation with the GBWR
110 coach which consisted of four participants (classification points totalling 8.0), with
111 games refereed by an official following IWRf regulations (International Wheelchair
112 Rugby Federation, International Rules for the Sport of Wheelchair Rugby June
113 (2013). In Internet:
114 [http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf)
115 [2015_English.pdf](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf); (10th November 2015)).

116 The match was played on a standard indoor basketball court and consisted of four 8
117 minute quarters with the game clock stopped during any stoppages or when the ball
118 was out of play, in accordance with IWRF regulations (International Wheelchair
119 Rugby Federation, International Rules for the Sport of Wheelchair Rugby June
120 (2013). In Internet:
121 [http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf)
122 [2015_English.pdf](http://www.iwrf.com/resources/iwrf_docs/Wheelchair_Rugby_International_Rules_2015_English.pdf); (10th November 2015)).

123 To obtain a continuous trace of T_{core} data, Cortemp data recorders (HQ Inc, Palmetto,
124 Florida) were attached in a secure position to the wheelchairs of up to three
125 participants per match, due to the availability of Cortemp data recorders. Due to a
126 disruption in connection between the pill and recorder the authors were not able to
127 obtain continuous data sets for all players, thus T_{core} values for the end of each
128 quarter were analysed. Therefore a total of seven matches were monitored. The
129 range of environmental conditions of the seven matches were 18.4 - 20.9°C and 31.1
130 – 45.1% relative humidity. Participants were required to play the full duration of the
131 match and were not permitted to use any form of cooling strategy.

132 *Activity profiles.* A radio-frequency based indoor tracking system (ITS, Ubisense,
133 Cambridge, UK) was used to provide real-time analysis of WCR activity profiles [25,
134 31]. Briefly, each participant was equipped with a small, lightweight tag (25g) fitted
135 into the back of a global positioning system vest that communicated with six sensors
136 through ultra-wideband signals. Data collection commenced at the beginning and
137 terminated at the end of each quarter and was paused during periods of extended
138 stoppages (e.g. time-outs, equipment breaks), resulting in a mean collection time of
139 17.5 ± 1.5 min/quarter.

140 Total distance travelled (m), distance travelled relative to time spent on court
141 ($\text{m}\cdot\text{min}^{-1}$) and mean and peak speed were determined for each participant. Using the
142 mean peak speed (V_{max}) from the match, five arbitrary speed zones were
143 individualised for each participant, as previously described [31]; very low ($\leq 20\%$
144 V_{max}), low (21-50% V_{max}), moderate (51-80% V_{max}), high (81-95% V_{max}) and very
145 high ($\geq 95\%$ V_{max}). The percentage of total match time spent in each speed zone was
146 determined for each individual. High intensity activities (HI, high and very high
147 speed zones) were extended to include the total number and distance covered during
148 these activities.

149 *Thermoregulatory measures.* Participants ingested a telemetry pill (HQ Inc, Palmetto,
150 Florida) for the measurement of core temperature (T_{core}) ~6-8 h prior to the start of
151 the match, to avoid the influence of ingested food or fluid on the temperature reading
152 in accordance with previous recommendations [4]. All matches were played at a
153 similar time in the afternoon to negate circadian variation [37]. Participants were
154 weighed before and after the match to the nearest 0.1 kg (Detecto, Cardinal Scale
155 Manufacturing Co., Webb City, Missouri, USA) and wore their usual competition
156 attire. Participants were allowed to drink *ad libitum* during breaks between quarters
157 and the volume of fluid was recorded. In addition to the absolute change in body
158 mass ($\text{Mass}_{\text{pre}} - \text{Mass}_{\text{post}}$), the change in body mass relative to fluid consumed (total
159 mass loss) was also calculated ($(\text{Mass}_{\text{pre}} - \text{Mass}_{\text{post}}) + \text{fluid consumed}$).

160 Core temperature was measured by Cortemp data recorders at the end of each quarter,
161 by averaging three values taken over a 1 min period.. The rate of change in T_{core} was
162 calculated by the change in T_{core} over a quarter divided by the total time of the
163 quarter. Seven iButtons (DS1922T, Maxim Integrated Products, Inc., Sunnyvale, CA,
164 USA) were applied to the forehead and on the right side of the body at the forearm,

165 upper arm (bicep), upper back, chest, thigh and calf prior to the 30 min warm-up led
166 by the coach.

167 In addition to individual skin temperatures, to compare to existing SCI literature,
168 mean skin temperature (T_{sk}) was calculated in accordance with the formula by
169 Ramanathan [30]. Convective (h_c) and evaporative (h_e) heat transfer coefficients
170 were calculated using the following equations for a seated person [20]:

$$h_c (Wm^{-2} \cdot C^{-1}) = 8.3 (v)^{0.6} \quad (1)$$

$$h_e (Wm^{-2} \cdot C^{-1}) = 16.5h_c \quad (2)$$

171 Where: v is the estimated player mean speed in $m \cdot s^{-1}$ from the ITS.

172 *Heart rate and perceptual measures.* Heart rate (HR) was continually recorded at 5 s
173 intervals (Polar PE 4000, Kempele Finland). Thermal sensation [35] was recorded at
174 the start of the match (categories ranged from 0.0 [“unbearably cold”] to 8.0
175 [“unbearably hot”] in 0.5 increments) and at the end of each quarter in addition to
176 ratings of perceived exertion (RPE, Borg scale) [3].

177 *Metabolic energy expenditure*

178 Metabolic energy expenditure (M) during the match was estimated using the minute-
179 average values for oxygen consumption ($\dot{V}O_2$) in litres per minute and the respiratory
180 exchange ratio (RER) during the $\dot{V}O_{2peak}$ test. The metabolic cost of pushing at the
181 mean speed during each quarter was calculated from the plot of oxygen consumption
182 vs. mean speed using these data. Metabolic energy expenditure was calculated using
183 the equation below:

$$M (W) = \dot{V}O_2 \frac{\left(\frac{RER-0.7 \cdot e_c}{0.3}\right) + \left(\frac{1-RER \cdot e_f}{0.3}\right)}{60} \cdot 1000 \quad (3)$$

184 Where: e_c is the caloric equivalent per litre of oxygen for the oxidation of
185 carbohydrates (21.13 kJ), and e_f is the caloric equivalent per litre of oxygen for the
186 oxidation of fat (19.62 kJ).

187 *Statistical analysis*

188 Data analysis was performed using the Statistical Package for the Social Sciences
189 (SPSS version 22, Chicago, IL) and all data are presented as mean \pm SD. Normality
190 and homogeneity of variance were confirmed by Shapiro–Wilk and Levene’s test,
191 respectively. One participant from the SCI group was stopped during the match due
192 to reaching the safety limit of a high T_{core} (39.5°C). Thus data analysis for SCI used
193 nine participants, except for the correlations between activity profiles, physical
194 attributes and end of match T_{core} where analysis was based on all ten participants.
195 Independent t-tests were used to analyse differences between SCI and NON-SCI in
196 participant characteristics, activity profiles, heat transfer coefficients and fluid
197 balance. Speed zones, heart rate, ΔT_{core} , ΔT_{sk} , change in individual skin temperatures,
198 and perceptual responses were analysed using a mixed method analysis of variance
199 (ANOVA). For all comparisons where the assumption of sphericity was violated, a
200 Greenhouse–Geisser correction was applied. Where significance was obtained post-
201 hoc pairwise comparisons with a Bonferroni correction were conducted. Main effects
202 and interactions were accepted as statistically significant when $p \leq 0.05$. Confidence
203 intervals (95% CI) for differences are presented, alongside effect sizes (ES) to
204 supplement important findings. Effect sizes were calculated as the ratio of the mean
205 difference to the pooled standard deviation of the difference. The magnitude of the
206 ES was classed as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0)
207 and very large (≥ 2.0) based on previous guidelines [2]. Pearson’s product-moment

208 correlation test was used as appropriate. An *a priori* power analysis, conducted in
209 G*Power 3.1, revealed a sample size of 14 participants was required, with 90%
210 power and an α of 5%, based on findings from previous research [13].

211 **Results**

212 *Participant characteristics*

213 The two groups were similar in terms of body mass ($p = 0.63$) and sum of skinfolds
214 ($p = 0.39$). Yet SCI were older ($p = 0.04$), demonstrated a lower $\dot{V}O_{2\text{peak}}$ ($p = 0.01$)
215 and functional class than NON-SCI ($p = 0.01$, Table 1).

216 *Insert Table 1 here*

217 *Activity profiles*

218 Total ($p < 0.01$, ES = 2.2, 95% CI = - 1045.5 to -352.5) and relative distances ($p =$
219 0.03, ES = 1.2, 95% CI = -15.5 to 0.9) travelled and mean speed ($p = 0.03$, ES = 1.3,
220 95% CI = -0.3 to -0.1) revealed large ES and were significantly lower in SCI
221 compared to NON-SCI. Peak speed ($p = 0.10$, ES = 0.8, 95% CI = -0.8 to 0.1),
222 number of HI activities ($p = 0.57$, ES = 0.4, 95% CI = -16.3 to 8.3) and total distance
223 of the HI activities ($p = 0.24$, ES = 0.7, 95% CI = -136.9 to 28.9) were not
224 statistically different between groups (Table 2).

225 *Insert Table 2 here*

226 The two groups did not differ in the percentage of total quarter time spent in each
227 speed zone ($p > 0.05$). There was no difference across all 4 quarters in the
228 percentage of time spent in each speed zone, except SCI spent a significantly smaller
229 percentage of time in the high speed zone in the first quarter than NON-SCI ($0.8 \pm$
230 0.4% vs. $1.8 \pm 0.7\%$; $p < 0.01$).

231 *Thermoregulatory measures*

232 The absolute change in body mass was significantly greater in SCI than NON-SCI (p
233 = 0.05, ES = 1.1), whilst there was no difference between groups for the amount of
234 fluid ingested (p = 0.75, ES = 0.1). Total mass loss was significantly lower in SCI
235 than NON-SCI (p = 0.04, ES = 1.1).

236 Prior to the warm-up ($37.0 \pm 0.4^\circ\text{C}$ vs. $37.4 \pm 0.5^\circ\text{C}$, p = 0.01, ES = 0.90) and start of
237 the match ($37.6 \pm 0.4^\circ\text{C}$ vs. $38.1 \pm 0.3^\circ\text{C}$ prior to start of the match; p < 0.01, ES =
238 1.4), absolute T_{core} was lower in SCI compared to NON-SCI. During the match the
239 change in T_{core} was greater ($1.6 \pm 0.4^\circ\text{C}$ vs. $0.7 \pm 0.3^\circ\text{C}$ from the start to the end of
240 the match, p < 0.01, ES = 2.5, 95% CI = 0.5 to 1.3, Fig. 1). A large ES for final T_{core}
241 revealed warmer end T_{core} in SCI than in NON-SCI ($39.3 \pm 0.5^\circ\text{C}$ vs. $38.8 \pm 0.3^\circ\text{C}$; p
242 = 0.06, ES = 1.7, 95% CI = 0.1 to 1.0). The rate of change in T_{core} was greater in SCI
243 than NON-SCI over each quarter (p < 0.01).

244

Insert Fig.1 here

245 Mean skin temperature was similar between groups at the start of the match ($30.78 \pm$
246 0.80°C vs. $32.59 \pm 1.15^\circ\text{C}$ for SCI and NON-SCI respectively, p = 0.68, ES = 1.9).
247 The change in T_{sk} was not different between groups or over time during the match
248 (Fig. 2, ES = 0.2, p > 0.05, 95% CI = -0.6 to 0.9). In SCI, Fig. 2 shows T_{sk} increased
249 at the end of quarter 2, whilst after an initial increase T_{sk} started to decrease at the
250 end of quarter 2 in NON-SCI. Changes in forearm, upper arm, chest, back, thigh and
251 calf skin temperatures during the match were similar between groups (all p > 0.05),
252 yet a main effect of time was only revealed for the forearm, upper arm and back (all
253 p < 0.05). The convective and evaporative heat transfer coefficients were
254 significantly lower for SCI than NON-SCI (p = 0.03).

255

Insert Fig. 2 here

256 *Heart rate and perceptual measures*

257 Heart rate was significantly lower in SCI than NON-SCI (100 ± 20 bpm vs. 143 ± 27
258 bpm; $p < 0.01$), yet there was no main effect of group or time for RPE ($p > 0.05$) or
259 thermal sensation ($p > 0.05$). During the match, RPE increased from 13 to 16 and 12
260 to 16 whilst thermal sensation increased from 4 to 6 and 4 to 7 in SCI and NON-SCI,
261 respectively. Significant relationships were only apparent between the change in core
262 temperature with both thermal sensation ($r = 0.37$, $p = 0.02$) and RPE ($r = 0.82$, $p <$
263 0.01) for SCI. Thermal sensation was significantly negatively correlated with the
264 change in mean skin temperature for SCI ($r = -0.47$, $p < 0.01$).

265 *Metabolic energy expenditure*

266 Differences between groups in metabolic energy expenditure did not reach
267 significance, but revealed a moderate ES (158 ± 44 W and 200 ± 74 W for SCI and
268 NON-SCI, respectively, $p = 0.21$, ES = 0.7, 95% CI = -105.5 to 21.5).

269 *Identifying WCR players under greatest thermal strain*

270 For the seven SCI participants that underwent the DXA procedures, body mass was
271 65.8 ± 4.2 kg, body surface area was 1.85 ± 0.11 m², lean tissue mass was 46.2 ± 6.6
272 kg and $70.2 \pm 9.0\%$ and fat mass was 16.3 ± 5.3 kg and $26.2 \pm 8.9\%$. Relationships
273 between key variables are shown in Fig. 3. Thermal sensation and RPE were not
274 correlated with any of the activity profile measures, end T_{core} or physical attributes.

275

Insert Fig. 3A +4B

276 **Discussion**

277 This study, to our knowledge, is the first comparison of both the physiological
278 responses and activity profiles of players with a SCI and a NON-SCI during
279 competitive WCR. Using this novel approach, findings revealed that players with a
280 SCI experienced greater thermal strain than NON-SCI players despite covering ~17%
281 less distance and pushing on average ~10% slower. Therefore, confirming our
282 primary hypothesis, players with a SCI were under a greater amount of thermal strain
283 compared to their NON-SCI teammates mainly due to the reduction in heat loss
284 capacity as a result of their impairment and not by the amount of work performed.

285 In line with previous data, players in the current study spent ~80% of total quarter
286 time in the very low/low speed zones [31], with both groups spending a similar
287 percentage of total quarter time in each speed zone. Nevertheless, the lower mean
288 speed of SCI, and thus lower self-generated air flow, would have caused
289 significantly lower dissipation of heat by convection and evaporation, depicted by
290 the lower heat transfer coefficients. Furthermore, evaporative heat loss would be
291 minimal for SCI [9, 23], given the large body surface area of insensate skin. In
292 relation to heat generation, although metabolic energy expenditure was not
293 significantly different, the observed moderate effect size (ES = 0.7) implies that
294 metabolic energy expenditure tended to be lower in SCI than NON-SCI during the
295 match. Thus, this suggests that heat production would also likely be lower. Field-
296 based testing has the benefit of testing players in their natural environment making
297 the results more relevant than laboratory testing. However, to ensure minimal
298 disturbance to the players, energy expenditure could not be measured during the
299 match and thus estimations of energy expenditure were taken from $\dot{V} O_{2peak}$
300 laboratory data. Nevertheless, combining the effects of both a loss of sweating
301 capacity and lower mean speed suggests players with a SCI are predisposed to a

302 greater increase in T_{core} than NON-SCI, despite NON-SCI expending more energy
303 and potentially producing more heat during match play.

304 For NON-SCI, the production and evaporation of sweat triggered by the rising T_{core}
305 would have caused a dissipation of heat lowering skin temperature, with the
306 increasing heat loss leading to the stabilisation of T_{core} by half-time [36]. Therefore,
307 effective heat loss occurred in NON-SCI, whilst the opposite was the case for SCI.
308 Due to the inactivation of the leg muscle pump, loss of sweating capacity and
309 vasomotor control below the lesion level [8, 17, 23], players with a SCI are unable to
310 dissipate the majority of heat produced through exercise leading to a continual
311 increase in T_{core} and T_{sk} [13, 27, 29, 36]. Thus, convective heat loss through muscle
312 and skin blood flow, in addition to evaporative heat loss through sweating below the
313 lesion would be limited.

314 The warmer T_{core} at the end of the match ($39.3 \pm 0.5^{\circ}\text{C}$), coupled with the larger rate
315 of rise of T_{core} for SCI during WCR match play highlights the greater thermal strain.
316 Although it has been shown that able-bodied athletes can operate at greater core
317 temperatures during exercise without any sign of fatigue or heat illness [7], whether
318 a similar critical core temperature exists for players with tetraplegia is currently
319 unknown. For instance, anecdotally the player that was stopped at 39.5°C displayed
320 noticeable difficulties with decision-making during play. Of practical importance,
321 T_{core} in athletes with tetraplegia continues to increase following exercise [13],
322 therefore a T_{core} of 39.3°C could be an additional concern if multiple matches are
323 played in succession, thus players will be starting the second match significantly
324 warmer than resting levels.

325 Despite players with a SCI having a greater increase in T_{core} and T_{sk} during match
326 play they did not perceive to be any warmer than NON-SCI. Significant relationships
327 between the change in T_{core} and thermal sensation and RPE were however apparent
328 for SCI. These relationships may be due to the concomitant and continuous increase
329 in T_{core} , thermal sensation and RPE during match play and may not represent a causal
330 relation. In able-bodied individuals, thermal sensation is largely dictated by skin
331 temperature, independent of T_{core} [33], yet a significant negative relationship was
332 apparent between the change in T_{sk} and thermal sensation for SCI. During exercise a
333 larger change in skin temperature may be needed to induce a change in thermal
334 sensation of similar magnitude [10, 24] or due to only a small portion of their body
335 (head, anterior of arms and shoulders) being sensate, the role of skin temperature for
336 thermal perceptions may be limited to a small surface area in SCI [1]. Whether
337 thermal sensation in SCI would have reflected dynamic changes in T_{sk} is unknown.
338 A better understanding of thermal perceptions in SCI is greatly needed to assist
339 coaches and medical staff to gauge when and which players should be removed from
340 play due to thermal strain, as the results suggest that the players themselves cannot
341 judge their thermal strain reliably.

342 A limitation of the study may have been the inclusion of only one female WCR
343 player. Despite this being reflective of the GBWR squad at the time, her change in
344 T_{core} and T_{sk} was similar to a player of the same classification (0.5) being, on average,
345 0.4°C and 0.2°C different, for T_{core} and T_{sk} , respectively, over the course of the match.
346 Thus, her inclusion in the study is justified, especially as large inter-individual
347 variation in thermoregulatory responses is common for individuals with a SCI [28,
348 29].

349 Preliminary data from the current study aimed to determine if certain physical
350 attributes or activity profiles were related to T_{core} at the end of the match in SCI.
351 Multifactorial inter-individual variability makes it challenging to determine factors
352 that predict heightened thermal strain [11]. However, the present study attempted to
353 enable the coach and support staff to identify WCR players at the greatest thermal
354 strain. From the correlation data for SCI, those with a greater $\dot{V}O_{2\text{peak}}$, larger body
355 mass, larger lean mass and body surface area, and/or were a higher point player,
356 showed a greater end T_{core} . Of note in SCI, an individual with a larger body mass
357 likely indicates a larger amount of upper body mass due to muscular atrophy below
358 the lesion. In relation to functional ability, a greater end T_{core} was apparent for higher
359 point players covering a greater relative distance and mean speed, i.e. generating a
360 greater amount of metabolic heat. Therefore, within the SCI group, it is the players
361 with a greater amount of functional ability, typically linked to roles on court that
362 elicit greater distances and speeds that are under the greatest thermal strain. In fact
363 the player that was stopped due to a high T_{core} ($>39.5^{\circ}\text{C}$) was a high point player and
364 had the greatest body mass and $\dot{V}O_{2\text{peak}}$ in the SCI group. Although the low number
365 of participants used to identify WCR players under the greatest thermal strain does
366 make drawing firm conclusions difficult, as a preliminary data set it does provide
367 greater detail and guidance for coaches and support staff on which players may need
368 greater attention in regards to cooling strategies or breaks in play.

369 **Conclusion**

370 The current study revealed that WCR players with a SCI are under a greater amount
371 of thermal strain compared to NON-SCI players during match play. Players with an
372 SCI covered less distance and had slower mean speeds, thus generating a smaller

373 amount of heat than NON-SCI. Yet, these players were under greater thermal strain,
374 due to a reduction in heat loss capacity as a result of their SCI. Preliminary data
375 revealed players with a SCI with greater functional ability (high point players) tend
376 to produce more heat during play and be predisposed to a greater T_{core} response than
377 low point players. Practically, coaches and support staff should be aware of the
378 greater thermal strain experienced by these players and implement appropriate
379 cooling strategies and tactics.

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398 Table 1. Physical attributes and participant characteristics of the two groups of
 399 wheelchair rugby players; spinal cord injured (SCI) and non-spinal related physical
 400 impairment (NON-SCI).

	SCI	NON-SCI	p value
		Including Cerebral	
Disability/ level of SCI	C5/6 - C7 (2 incomplete)	Palsy (n=2), lower limb deficiency (n=4) and leg amputation (n=1).	
Age (years)	30 ± 5*	23 ± 5	p = 0.04
Body mass (kg)	68.4 ± 10.5	65.3 ± 14.8	p = 0.63
Sum of four skinfolds (mm)	57.3 ± 30.6	51.0 ± 13.6	p = 0.39
$\dot{V}O_{2peak}$ (L·min⁻¹)	1.4 ± 0.3*	2.4 ± 0.7	p = 0.01
Training (h·week⁻¹)	14 ± 4	10 ± 4	p = 0.09
Classification	0.5-2.5*	1.5-3.5	p = 0.01

401 *significantly different to NON-SCI, p ≤ 0.05.

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408 Table 2. Match play activity profiles during the wheelchair rugby match for spinal
 409 cord injured (SCI) and non-spinal related physical impairment (NON-SCI).

	SCI	NON-SCI	p value
Total distance (m)	4842 ± 324*	5541 ± 316	p < 0.01
Relative distance (m·min⁻¹)	68.1 ± 7.0*	76.3 ± 6.4	p = 0.03
Mean speed (m·s⁻¹)	1.13 ± 0.11*	1.27 ± 0.11	p = 0.03
Peak speed (m·s⁻¹)	3.42 ± 0.50	3.76 ± 0.18	p = 0.10
Number of HI activities	22 ± 10	26 ± 13	p = 0.57
Total distance of HI activities (m)	134 ± 45	188 ± 105	p = 0.24

410 HI = high intensity activities, combination of high (81-95% Vmax) and very high
 411 (≥95%Vmax) speed zones.

412 *significantly different to NON-SCI, p ≤ 0.05.

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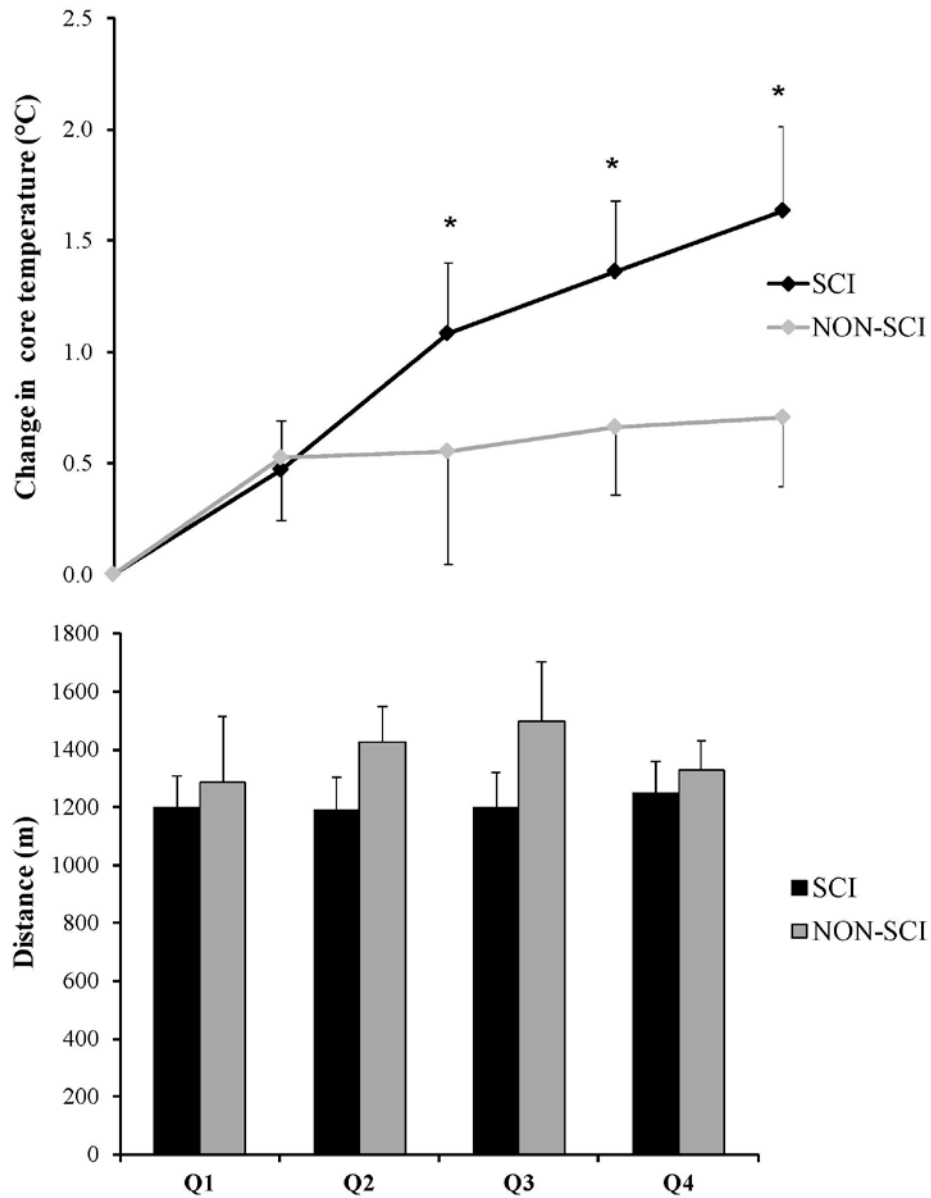
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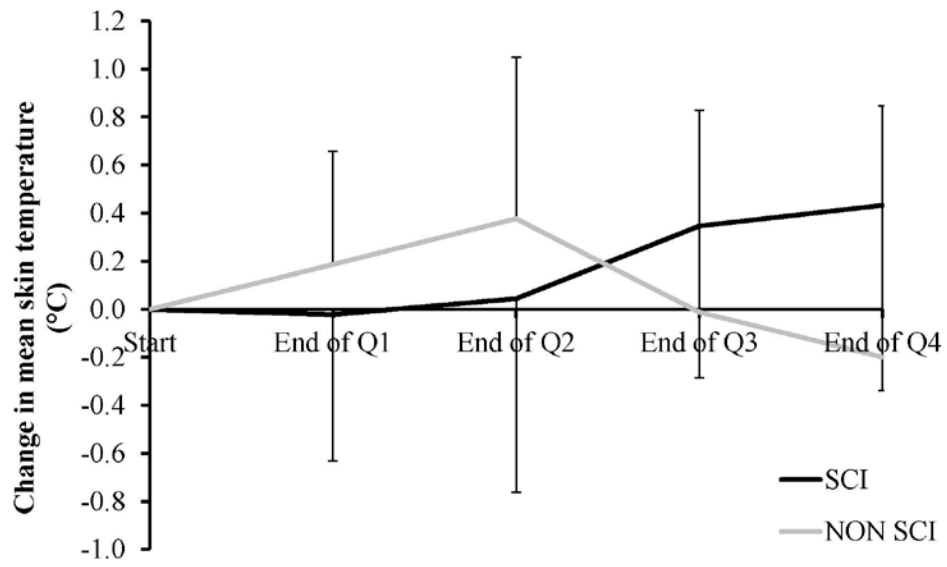
437 Fig.1 Distance travelled and change in core temperature over duration of the match
 438 for spinal cord injured (SCI) and non-spinal related physical impairments (NON-
 439 SCI). Q = quarter. * significantly different to NON-SCI, $p \leq 0.05$.

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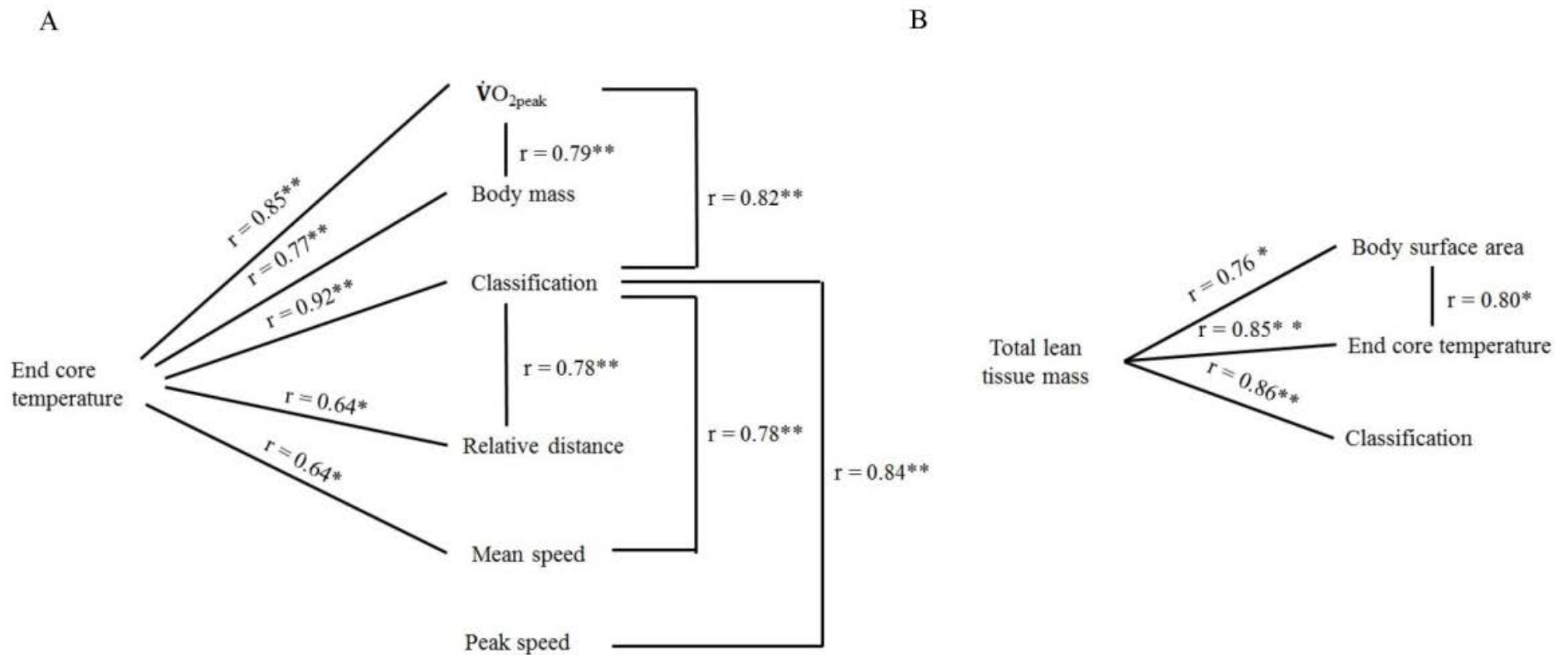
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450 Fig.2 Change in mean skin temperature over the duration of the match for spinal
451 cord injured (SCI) and non-spinal related physical impairments (NON-SCI). Q =
452 quarter. *significantly different to NON-SCI, $p \leq 0.05$.



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454 Fig.3 A) Relationship for spinal cord injured (n=10) between participant characteristics, physical attributes, activity profiles and thermal
 455 measures. B) Relationship for spinal cord injured (n=7) between dual-energy X-ray absorptiometry measures, participant characteristics and
 456 thermal measures. $\dot{V}O_{2peak}$ = peak oxygen uptake, * = significantly different at $p \leq 0.05$, ** = significantly different at $p \leq 0.01$.

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