Thermoregulatory Responses during Competitive Wheelchair Rugby Match Play

Abstract

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

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

Introduction

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

Studies have shown IWRF classification to be closely related to the volume of activity elicited over a typical WCR quarter [31, 32, 34]. For example, high point players (2.0-3.5 points) are capable of greater peak speeds and spend less time within low speed zones compared to low point players (0.5-1.5 points) [31]. Furthermore, high point players are shown to have better ball-handling skills, such as interceptions and passes made and caught [21, 22], most likely attributed to these players occupying offensive rather than defensive roles [31]. Interestingly, despite the noted thermoregulatory impairment of individuals with tetraplegia, no study to date has examined the combination of thermal strain of WCR players during match play and the associated activity profiles. Individual thermoregulatory outcomes during exercise may be influenced by independent factors, such as the physical attributes of body mass and body composition [16]. Although, it has also been suggested that a smaller percentage of individual variability in thermoregulatory responses is explained by body composition in the able-bodied [5], due to the atrophy of skeletal muscle in the lower limbs, whether the same variability exists for individuals with a SCI is currently unknown.

Whether a player's physical impairment, activity profile or physical attributes predisposes them to a greater amount of thermal strain during match play has both a practical and clinical importance. For instance, identifying players under greater thermal strain could enable both the implementation of targeted cooling strategies and a reduction in performance decrements due to a high core temperature. Furthermore, by investigating players during actual match play a physical challenge and psychological stress is attained that is difficult to replicate in a laboratory. Thus the purpose of this study was twofold 1) to compare the thermoregulatory responses and activity profiles of players with a SCI to those players with a NON-SCI during competitive WCR and 2) in those players with a SCI determine whether their classification, activity profile and/or physical attributes were related to the thermal strain experienced during competitive WCR. It was hypothesized that 1) players with a SCI would be under a greater amount of thermal strain than players with a NON-SCI during competitive WCR and 2) due to the greater activity levels of high point players reported previously [31], high point players with a SCI would experience a heightened thermal response.

Methods

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

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

Laboratory testing

Peak oxygen uptake ($\dot{V}O_{2peak}$). The incremental exercise test was completed on a motorised treadmill (HP Cosmos, Traunstein, Germany) at a constant 1.0 % gradient as previously described [19]. In brief, the speed was continually increased by 0.2-0.4 $m \cdot s^{-1}$ every 3 min, dependent on the participant's level of impairment. A slower starting speed and smaller speed increments were adopted for SCI players with higher lesion levels (e.g. C5/6) and lower point players (e.g. 1.5) for NON-SCI. The test was terminated when participants were unable to maintain the speed of the treadmill.

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

Field testing

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

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

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

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

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

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

Core temperature was measured by Cortemp data recorders at the end of each quarter, by averaging three values taken over a 1 min period.. The rate of change in T_{core} was calculated by the change in T_{core} over a quarter divided by the total time of the quarter. Seven iButtons (DS1922T, Maxim Integrated Products, Inc., Sunnyvale, CA, USA) were applied to the forehead and on the right side of the body at the forearm, upper arm (bicep), upper back, chest, thigh and calf prior to the 30 min warm-up led by the coach.

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

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

$$\mathrm{h}_e\,(Wm^{-2}\cdot C^{-1}) = \,16.5h_c \qquad (2)$$

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

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

Metabolic energy expenditure

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

$$M\,(\mathrm{W}) = \,\dot{VO}_2\,\frac{\left(\frac{RER-0.7\,\cdot \mathrm{e}_c}{0.3}\right) + \left(\frac{1-RER\,\cdot e_f}{0.3}\right)}{60}\cdot 1000 \qquad (3)$$

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

Statistical analysis

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS version 22, Chicago, IL) and all data are presented as mean ± SD. Normality and homogeneity of variance were confirmed by Shapiro–Wilk and Levene's test, respectively. One participant from the SCI group was stopped during the match due to reaching the safety limit of a high T_{core} (39.5°C). Thus data analysis for SCI used nine participants, except for the correlations between activity profiles, physical attributes and end of match T_{core} where analysis was based on all ten participants. Independent t-tests were used to analyse differences between SCI and NON-SCI in participant characteristics, activity profiles, heat transfer coefficients and fluid balance. Speed zones, heart rate, ΔT_{core}, ΔT_{sk}, change in individual skin temperatures, and perceptual responses were analysed using a mixed method analysis of variance (ANOVA). For all comparisons where the assumption of sphericity was violated, a Greenhouse–Geisser correction was applied. Where significance was obtained post-hoc pairwise comparisons with a Bonferroni correction were conducted. Main effects and interactions were accepted as statistically significant when $p \leq 0.05$. Confidence intervals (95% CI) for differences are presented, alongside effect sizes (ES) to supplement important findings. Effect sizes were calculated as the ratio of the mean difference to the pooled standard deviation of the difference. The magnitude of the ES was classed as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0) and very large (⩾2.0) based on previous guidelines [2]. Pearson's product-moment correlation test was used as appropriate. An *a priori* power analysis, conducted in G*Power 3.1, revealed a sample size of 14 participants was required, with 90% power and an α of 5%, based on findings from previous research [13].

Results

Participant characteristics

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

Insert Table 1 here

Activity profiles

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

Insert Table 2 here

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

Thermoregulatory measures

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

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

Insert Fig.1 here

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

Insert Fig. 2 here

Heart rate and perceptual measures

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

Metabolic energy expenditure

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

Identifying WCR players under greatest thermal strain

For the seven SCI participants that underwent the DXA procedures, body mass was 65.8 ± 4.2 kg, body surface area was 1.85 ± 0.11 m^2, lean tissue mass was 46.2 ± 6.6 kg and 70.2 ± 9.0% and fat mass was 16.3 ± 5.3 kg and 26.2 ± 8.9%. Relationships between key variables are shown in Fig. 3. Thermal sensation and RPE were not correlated with any of the activity profile measures, end T_{core} or physical attributes.

Insert Fig. 3A +4B

Discussion

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

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

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

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

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

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

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

Conclusion

The current study revealed that WCR players with a SCI are under a greater amount of thermal strain compared to NON-SCI players during match play. Players with an SCI covered less distance and had slower mean speeds, thus generating a smaller amount of heat than NON-SCI. Yet, these players were under greater thermal strain, due to a reduction in heat loss capacity as a result of their SCI. Preliminary data revealed players with a SCI with greater functional ability (high point players) tend to produce more heat during play and be predisposed to a greater T_{core} response than low point players. Practically, coaches and support staff should be aware of the greater thermal strain experienced by these players and implement appropriate cooling strategies and tactics.

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

	SCI	**NON-SCI**	**p value**
Disability/ level of SCI	C5/6 - C7 (2 incomplete)	Including Cerebral 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	$p = 0.39$
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	1.4 ± 0.3*	2.4 ± 0.7	$p = 0.01$
Training ($h \cdot week^{-1}$)	14 ± 4	10 ± 4	$p = 0.09$
Classification	0.5-2.5*	1.5-3.5	$p = 0.01$

*significantly different to NON-SCI, $p \leq 0.05$.

Table 2. Match play activity profiles during the wheelchair rugby match for spinal 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 ($m \cdot min^{-1}$)	68.1 ± 7.0*	76.3 ± 6.4	$p = 0.03$
Mean speed ($m \cdot s^{-1}$)	1.13 ± 0.11*	1.27 ± 0.11	$p = 0.03$
Peak speed ($m \cdot s^{-1}$)	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	$p = 0.24$

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

*significantly different to NON-SCI, $p \leq 0.05$.

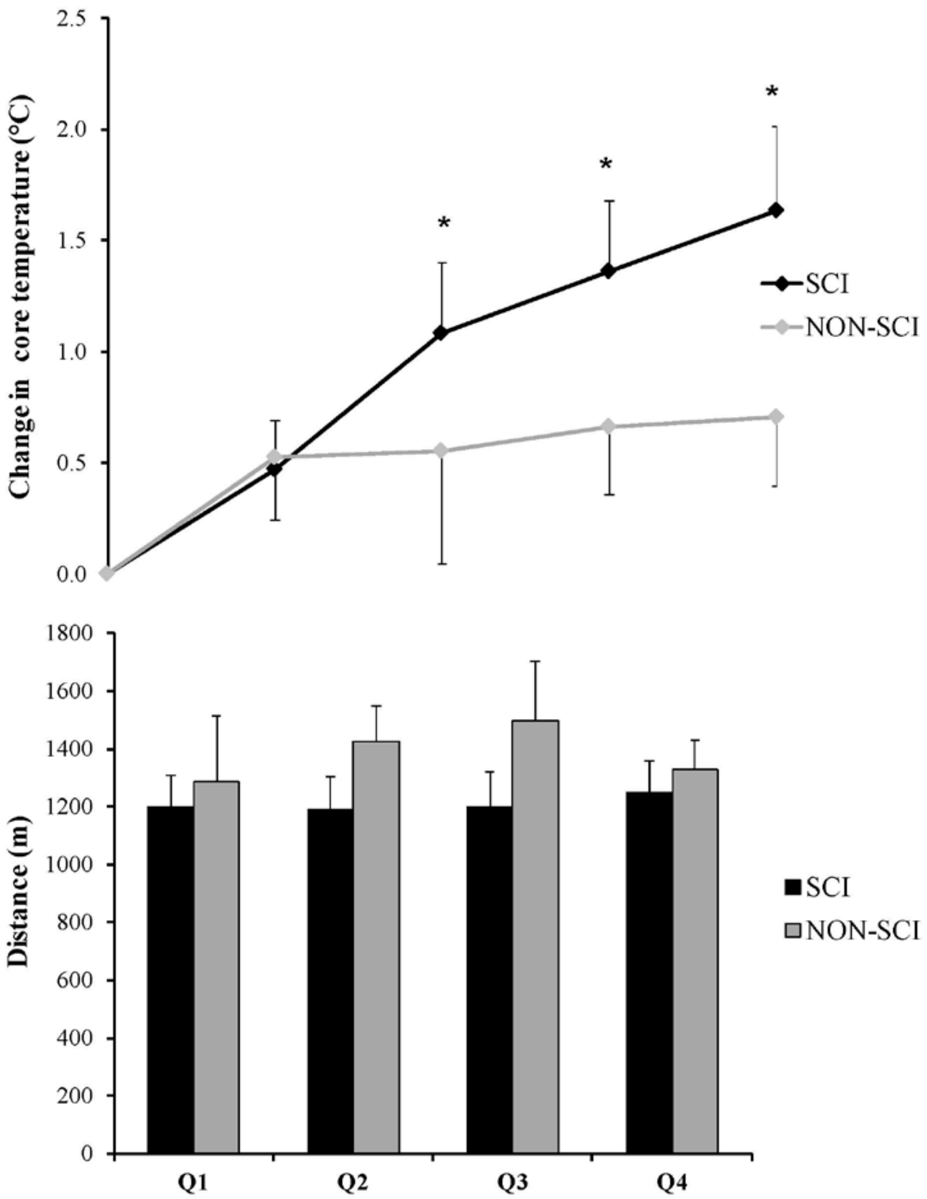


Fig.1 Distance travelled and change in core temperature over duration of the match for spinal cord injured (SCI) and non-spinal related physical impairments (NON-SCI). Q = quarter. * significantly different to NON-SCI, $p \leq 0.05$.

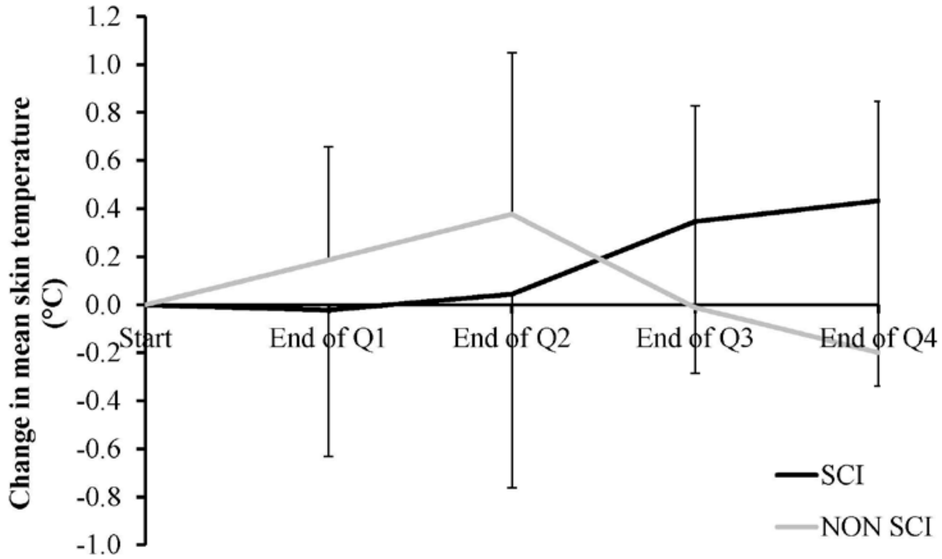
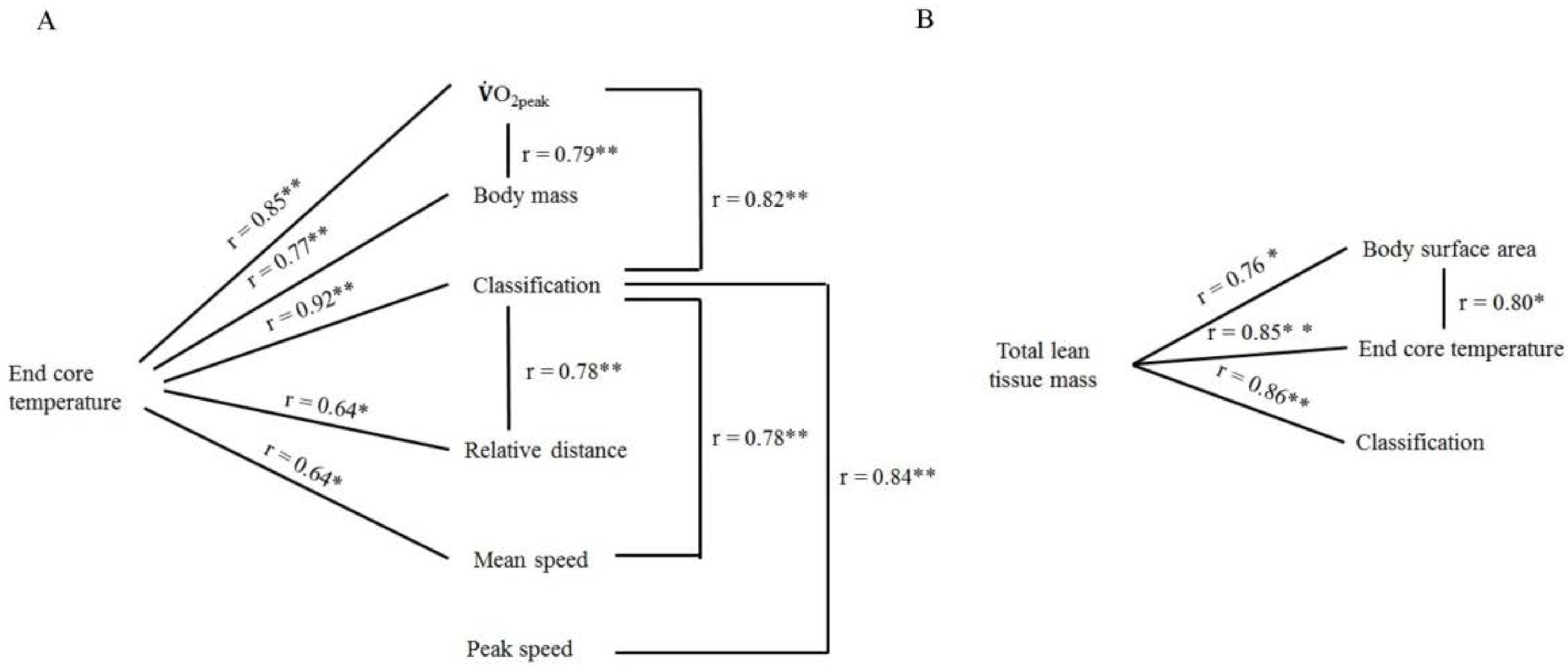


Fig.2 Change in mean skin temperature over the duration of the match for spinal cord injured (SCI) and non-spinal related physical impairments (NON-SCI). Q = quarter. *significantly different to NON-SCI, $p \leq 0.05$.



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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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