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Thermoregulation of paraplegic and able bodied men during prolonged exercise in hot and cool climates

B Dawson PhD, J Bridle MSc, R J Lockwood PhD

Exercise Physiology Laboratory, Department of Human Movement, University of Western Australia, Nedlands, 6009 Australia.

The purpose of this study was to compare the thermoregulatory responses of trained paraplegics (TP) and able bodied subjects (AB) performing submaximal exercise of the same relative intensity in both hot and cool conditions. Five TP (lesion range T12 to L3) and five AB subjects experienced in wheelchair use performed 60 minutes of constant load (55–60% of $\dot{V}O_2$ max) arm ergometry exercise in 37 °C and 15 °C climatic conditions. Heart rate (HR), sweat rate and rectal (Tr) and skin ($\bar{T}sk$) temperatures were recorded. In the hot climate the TP subjects recorded a significantly greater change in $\bar{T}sk$ ($\Delta\bar{T}sk$) from 0 to 60 minutes of exercise than the AB subjects, because of greater thigh and calf temperatures, but no other significant differences were found between these groups. In the cool climate no significant differences were observed between the TP and AB groups. It was concluded that TP have a similar thermoregulatory ability to AB subjects who perform identical prolonged exercise in hot and cool conditions, although their lower limb skin temperatures are greater, probably because of venous pooling in the legs. While these results are a promising indication of the ability of TP to thermoregulate effectively while exercising in the, heat caution regarding their participation in endurance competitions in hot conditions should be expressed until data collected during wheelchair exercise (rather than arm ergometry) in the heat is available.

Keywords: sweat rate; rectal and skin temperature; spinally injured; maximal oxygen consumption; arm cranking.

Introduction

Sport and exercise programmes are now assuming a larger role in the rehabilitation of the spinally injured, which has resulted in an increased participation in events traditionally reserved for the able bodied. Many of these sporting activities involve prolonged (60 min or more) exercise at intensities requiring greater than 50% of maximal oxygen consumption ($\dot{V}O_2$ max). The varied environmental conditions under which these activities are conducted also warrant consideration from the viewpoint of safety. For example, marathons require prolonged exercise at a high intensity of effort (greater than 70% $\dot{V}O_2$ max.),[1] and often must be performed in hot and/or humid conditions which places severe demands on the cardiovascular and thermoregulatory systems of the body.

When paraplegics expose themselves to such physiological strain and environmental stress, they may experience great difficulty in regulating their body temperature within safe limits. According to Seckendorf and Randall,[2] spinally injured persons have an impaired centrally-driven sweating response, with the extent of this impairment being related to the level of spinal lesion, and to the lowermost intact sympathetic connections. Despite the presence of local temperature reflexes originating in the skin, the spinal cord and from intra-abdominal receptors,[3] the extent to which the centrally driven sweating response is inhibited by the spinal lesion will ultimately have a marked influence on body temperature regulation during prolonged exercise. Therefore, although spinal reflex sweating[4] is present in the paraplegic below the level of the spinal lesion, it alone may not be powerful enough to regulate body temperatures within safe limits during prolonged exercise.

When paraplegics exercise in a hot environment, their reduced central sweating response may result in thermoregulatory strain which is not present in able bodied persons performing at the same exercise intensity in identical environmental conditions. In addition to a limited central sweating response, paraplegics will also have a reduced convective heat exchange as a result of their normal practice of competing in tracksuit pants. Whether paraplegics can regulate their body temperature at the same level as able bodied subjects performing identical exercise in the same environmental conditions has not been widely investigated. Only Fitzgerald *et al*,[5] who found paraplegic women experienced greater thermoregulatory strain than able bodied women when performing wheelchair ergometry in cool conditions have reported data on this topic.

Also, although the effects of acute and prolonged wheelchair exercise in cool environmental conditions have been investigated elsewhere,[6–9] the thermoregulatory responses of paraplegics performing prolonged physical exercise in hot conditions has not been studied. Therefore, it was the purpose of this study to investigate these questions by comparing the thermoregulatory responses of paraplegic and able bodied subjects to prolonged submaximal exercise in both hot and cool conditions.

Methods and procedures

Sample

Five trained male paraplegics (TP) and five able bodied (AB) males participated as subjects in the study. Their characteristics are presented in Table I. The paraplegic subjects were cleared to participate in the study by a medical registrar from the Royal Perth (Rehabilitation) Hospital. The TP were all members of a wheelchair basketball team, with three of them currently playing

Table I Mean (+ SD) characteristics of the two groups of subjects

Subjects	Age (y)	Height (cm)	Mass (kg)	Body surface area (m^2)[a]	Sum of 6 skinfolds[b]	Lesion level
Trained paraplegics (n = 5)	24.8 ± 3.7	179.0 ± 4.7	71.9 ± 7.5	1.90 ± 0.10	67.0 ± 19.5	1 L1 complete 4 T12–L1 incomplete
Able bodied subjects (n = 5)	26.0 ± 3.2	183.3 ± 5.4	86.8 ± 5.8	2.10 ± 0.09	68.5 ± 20.3	—

[a]Body surface area was calculated from the Dubois Nomogram.
[b]Skinfold sites were as per Telford *et al*,[21] except that thigh and calf sites were not used because of the characteristic leg atrophy of paraplegics.

for the Western Australian state wheelchair basketball team. All subjects had been training at least one night per week and playing at least one game of basketball per week for the past 3 months. Two of the subjects were also actively involved in training for disabled athletic events. Trained paraplegics were sought as subjects for this study as they are likely to possess better exercise-heat tolerance than untrained paraplegics, as is the case with trained and untrained able bodied persons.[10,11,12]

The AB subjects were members of a wheelchair basketball team and had been playing for a minimum of two seasons, thus were deemed to be 'experienced' wheelchair users. These persons were selected as subjects because they were accustomed to exercise utilising the upper body musculature, hence allowing for a better comparison of data between groups.

All subjects were fully informed of the experimental procedures and all gave their informed consent prior to performing any testing. The study was approved by the Human Rights Committee of the University of Western Australia.

Experimental design

The study consisted of three separate experimental stages; (1) maximal physiological profiling of each subject; (2) 60 min of constant load arm cranking at approximately 55–60% of each subject's $\dot{V}O_2$ max. (as determined from stage 1) in a hot, dry ($37.4 \pm 0.3\,°C$ T_{DB}; $24.4 \pm 0.3\,°C$ T_{WB}; $33.0 \pm 1.9\%$ RH) climate; and (3) an identical protocol as for stage 2, except that subjects exercised in a cool ($15.0 \pm 0.2\,°C$ T_{DB}; $10.5 \pm 0.2\,°C$ T_{WB}; $56.9 \pm 2.1\%$ RH) climate.

On average, each subject had a 7 day break between each stage. During stages 2 and 3 the tests and treatments for each subject were conducted at the same time of the day (± 1 h) to minimise variation due to the circadian rhythm of body temperature.[13]

Preliminary testing (stage 1)

A maximal arm crank test to volitional exhaustion was conducted on a Seimens-Elema 380B electromagnetically braked arm crank ergometer and performed in a controlled laboratory environment (21 °C, 50% RH). Each subject cranked in a seated upright position with the seat height standardised so that the crank shaft was 15 cm above the heart.[14] The placement of the seat, as recommended by Williams *et al*,[15] was such that it allowed a slight flexion at the elbow at the point of maximal pedal excursion. Also, straps were placed around each subject's thigh and ankles, and the seat height was such that the feet could not touch the floor. This was done to prevent the able bodied subjects from using their lower body musculature to achieve a more stable position while cranking.

The arm crank ergometer was set in constant power mode and the subject was instructed to crank at 70 revolutions per min (rpm). A comfortable workload (200 kpm min^{-1}) was selected for the first 3 min. At the end of the initial 3 min the workload was increased to 300 kpm min^{-1}. From this point on the workload was increased by 50 kpm min^{-1} every 2 min until volitional exhaustion.

Inspired volume ($\dot{V}_I$) was recorded by a Morgan Ventilometer Mark 2. The expired gas was simultaneously analysed for its oxygen (F_EO_2) and carbon dioxide (F_ECO_2) content with an Applied Electrochemistry S-3A oxygen analyser and Datex CD-101 carbon dioxide analyser. The F_EO2, F_ECO_2, $\dot{V}_{I\,(ATPS)}$ and $\dot{V}O_{2\,(STPD)}$ were recorded every 30 s. Heart rate (HR) was recorded in the last 10 s of each minute of the test, and in the final 10 s of exercise using a Siemens Cardiostat 701 electrocardiograph (ECG). Before each test the gas analysers were calibrated with gases of known concentrations (gravimetrically determined) and the Morgan Ventilometer was calibrated by drawing a known volume of air through it using a 1 litre syringe.

Blood lactate concentrations [Hla] were obtained from 25 μl capillary blood samples taken from the earlobe at 1, 3, 5 and 7 min post exercise, then analysed by an enzymatic oxidase method using an Analox LM3 multichannel analyser. Only the peak [Hla] value was recorded. A range of lactate standards 1 mmol l^{-1} to 15 mmol l^{-1} were routinely used to check the calibration of this analyser (mean coefficient of variation 1.5%).

Controlled climate testing (stages 2 and 3)

The workload intensity for the prolonged exercise tests in controlled climates (hot and cool) was set at a constant load equal to approximately 55–60% of each subject's $\dot{V}O_2$ max as determined from the maximum exercise test. The procedures, equipment and recording instruments used during the climate chamber test were identical for all subjects and for both tests. The only variation was in the environmental conditions existing in the chamber. The first prolonged exercise test was performed in the hot climate, and the second performed in the cool climate.

The subjects were stopped during any of these sessions if their rectal temperature (Tr) exceeded 39.5 °C, max HR was achieved, or they expressd a desire to cease because of exhaustion or discomfort. One paraplegic subject was unable to complete 60 min of exercise in the hot climate. This subject reached his max HR after 35 min and was immediately removed from the chamber. All subjects were able to successfully complete 60 min of exercise in the cool climate.

The subjects were prepared for the exercise tests in an air-conditioned laboratory with an ambient temperature of approximately 21 °C. On arrival at the climate chamber subjects drank 400 ml of distilled water in an attempt to standardise the initial level of hydration. Nude body mass (± 10 g) (Avery 3350 AAE beam balance) was taken, then the leads for the recording of Tr (YSI model 401, inserted 10 cm beyond the anal sphincter), mean skin temperature ($\bar{T}sk$) (YSI model 408/409B) and HR (ECG) were attached. A YSI Model 46 TUC Telethermometer was used for temperature measurements and the weighted equation of Ramanathan[16] was used for calculating $\bar{T}sk$.

Three min prior to entering the chamber a 25 μl sample of blood was taken from the earlobe to measure pre-exercise [Hla]. The method of collection was the same as described previously. The subjects then entered the climate chamber and were seated at the arm crank ergometer and strapped into position as in stage 1. Moving air (0.03 m s^{-1}) was directed at their faces during the tests.

Five minutes after entering the climate chamber the subjects began cranking at 70 rpm against a constant workload intensity set at approximately 55–60% of their $\dot{V}O_2$ max using a Seimens-Elema 380B electromagnetically braked arm crank ergometer set in constant power mode as for the maximal capacity test. They cranked continuously for 60 min, throughout which HR, $\bar{T}sk$, and Tr were measured every 5 min; [Hla] during the 30th min and 1 min post exercise; $\dot{V}O_2$ during the 19th, 39th and 59th min; and body mass 5 min post exercise (after removal of all leads and being towelled dry). The change in body mass (pre- to post-) was used to calculate sweat rate (g h^{-1}). No corrections were made for respiratory water loss or metabolic weight loss. In these tests $\dot{V}O_2$ was measured by collecting expired air for 1 min in a 120 litre chain compensated Tissot Tank. A sample of expired air was withdrawn from the gasometer using a 2 litre rubber gas bag and analysed for F_ECO_2 by a Datex Normocap carbon dioxide analyser and for F_EO_2 by a Beckman OM-11 oxygen analyser.

Treatment and analysis of the data

An independent *t*-test and a two-way ANOVA with repeated measures were used to determine the significance of any differences observed between groups on the maximal arm cranking test and for the thermoregulatory data recorded during the controlled climate tests. When appropriate, post-hoc analysis (Fisher's PLSD) was used. Polynomial contrasts were also employed to test the significance of differences between goups in Tr, $\bar{T}sk$, $\dot{V}O_2$ and HR responses over time in each climate. The statistical package used made data adjustments for the paraplegic subject who failed to complete 60 min of exercise in the hot climate. A significance level of $p < 0.05$ was set for all statistical decisions.

Results

A. Physiological responses to maximal exercise

Table II presents the mean (± SE) values for all variables measured during the performance of the maximal exercise capacity test for the two groups. The only significant difference ($p < 0.01$) found between the TP and AB subjects was for absolute $\dot{V}O_2$ max ($1\,min^{-1}$), with a greater value being recorded for the AB subjects. However, when $\dot{V}O_2$ was expressed in relative ($ml\,kg^{-1}\,min^{-1}$) terms, there was no significant difference between these two groups as the AB subjects on average were approximately 15 kg heavier than the TP. Maximum work time (WT) (min) and max workload (WL) ($kpm\,min^{-1}$) were very similar between TP and AB subjects.

B. Physiological responses to prolonged exercise in controlled climates

(a) Oxygen consumption

With duration of effort (19–59 min) both groups showed a significant ($p < 0.01$) increase in $\dot{V}O_2$ in the hot climate (TP: range 59 to 64% $\dot{V}O_2$ max and AB subjects: 56 to 64% $\dot{V}O_2$ max.), however, no significant increases in $\dot{V}O_2$ in the cool climate were evident (TP: range 57 to 60% $\dot{V}O_2$ max and AB subjects: 52 to 57% $\dot{V}O_2$ max). When between group comparisions were made there were no significant differences recorded in $\dot{V}O_2$ in either climate.

(b) Rectal temperature (Figure 1 shows these values)

As would be expected, both groups recorded a significant increase in Tr ($p < 0.01$) across the exercise period in the hot climate. Between group comparisons showed that there were no significant differences in Tr response in the TP and AB subjects. The ΔTr values for 0–60 min were 0.65 ± 0.12 °C in the TP and 0.70 ± 0.15 °C (NS) in the AB subjects.

In the cool climate both groups recorded significant linear and quadratic changes in Tr, exhibiting a plateau in Tr response, which indicated that they were able to achieve a steady state in core temperature. Between group comparsions showed there to be no significant differences in Tr response between the TP and AB subjects in the cool climate. The respective ΔTr values for 0–60 min (TP: 0.45 ± 0.10 °C and AB: 0.35 ± 0.04 °C) also showed no significant between-group differences.

(c) Mean skin temperature (Figure 2 shows these values)

The AB subjects exhibited a steady decline in $\bar{T}sk$ in the last 30 min of the exercise period in the hot climate in contrast to the TP who recorded a steady rise in $\bar{T}sk$

Table II Physiological responses of the trained paraplegics and able bodied subjects to maximal arm cranking exercise

Variable	Trained paraplegics	Able bodied subjects
$\dot{V}O_2$ max ($1\,min^{-1}$)	2.41 ± 0.06 (2.23–2.53)	2.83 ± 0.11** (2.43–3.05)
$\dot{V}O_2$ max ($ml\,kg^{-1}\,min^{-1}$)	33.7 ± 1.7 (21.6–38.4)	32.6 ± 1.1 (30.3–36.5)
Max WL ($kpm\,min^{-1}$)	600 ± 27 (500–650)	610 ± 37 (500–700)
Max WT (min)	16.2 ± 1.0 (12.5–18.0)	16.9 ± 1.4 (12.5–19.5)
Max HR (bpm)	188 ± 4 (173–197)	185 ± 6 (165–200)
Peak [Hla] ($mMol\,1^{-1}$)	11.4 ± 0.7 (9.4–12.8)	11.6 ± 0.5 (10.5–13.1)

**$p < 0.01$.
Values presented are $\bar{X}$ ± SEM and the range of values.

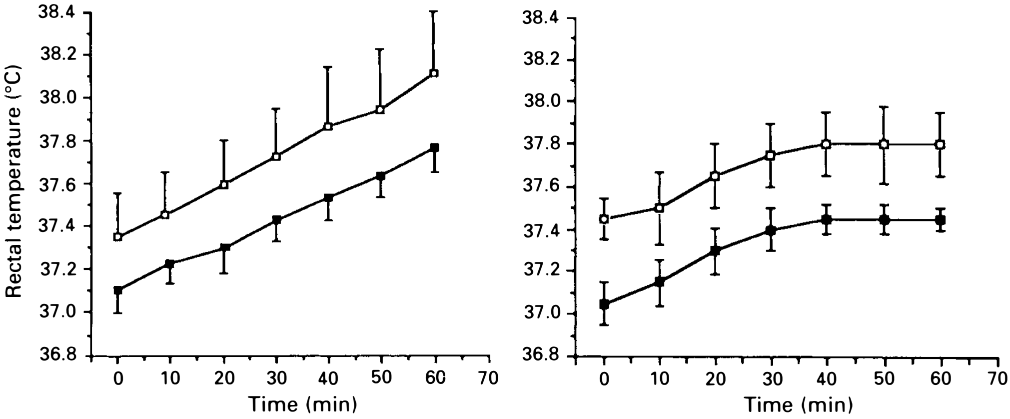

Figure 1 Mean (± SE) rectal temperature responses of trained paraplegics (TP: -■-) and able bodied (AB: -□-) subjects during submaximal exercise in hot (left panel) and cool (right panel) climates.

Note: Hot climate: Both groups showed a significant linear ($p < 0.01$) increase over the exercise period. There was no significant interaction between TP and AB subjects.

Cool climate: Both groups showed a significant ($p < 0.01$) linear and quadratic change over the exercise period. There were no significant interactions between the TP and AB subjects.

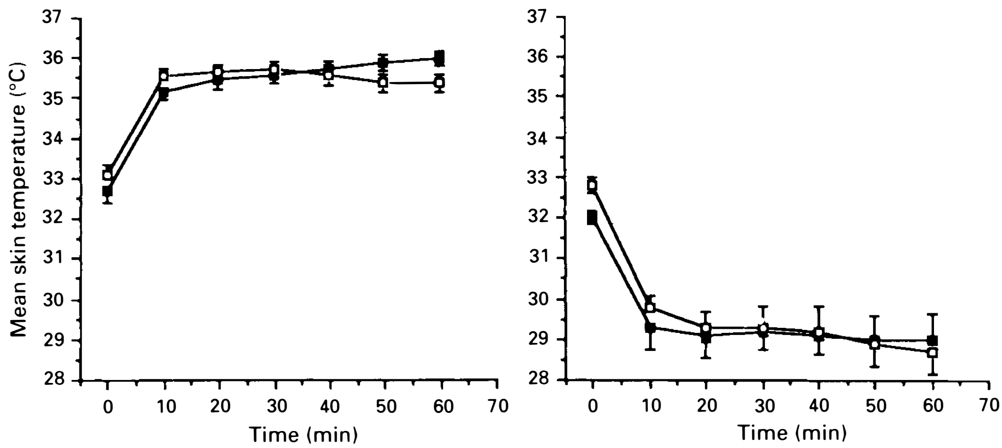

Figure 2 Mean (± SE) skin temperature responses of trained paraplegics (TP: -■-) and able bodied (AB: -□-) subjects during submaximal exercise in hot (left panel) and cool (right panel) climates.

Note: Hot climate: TP and AB subjects recorded a significant linear ($p < 0.01$) and quadratic ($p < 0.05$) change over the exercise period. A significant linear ($p < 0.01$) interaction was also recorded.

Cool climate: Both groups recorded a significant linear ($p < 0.01$) decrease over the exercise period. There were no significant interactions between the TP and AB subjects.

throughout. This resulted in a significant ($p < 0.01$) linear interaction between the two groups. The $\Delta\bar{T}sk$ values for 0–60 min support this finding as the AB subjects recorded a value of 2.25 ± 0.32 °C, which was significantly lower ($p < 0.05$) than the TP (3.55 ± 0.23 °C).

In the cool climate both groups recorded a significant decrease ($p < 0.01$) in $\bar{T}sk$ across the exercise period. However, the between group comparisons showed that there were no significant interactions present. The $\Delta\bar{T}sk$ values 0–60 min also showed no significant differences (TP: 3.10 ± 0.38 °C and AB: 4.10 ± 0.51 °C) between groups.

(d) Heart rate (Figure 3 shows these results)
Heart rates were approximately 80–90% max HR in the hot climate and approximately 65–70% max HR in the cool climate. A steady increase in HR across the exercise period was evident in each group in both climates (cardiovascular drift), with the exception of the AB subjects in the cool climate, who recorded a slight decrease in HR in the last 10 min of exercise. Between group comparisons showed there to be no significant differences in HR response between the TP and AB subjects in either climate.

(e) Blood lactic acid concentration (Table III shows these values)
In both climates the two groups recorded their highest [Hla] values after 30 min of exercise, with the subsequent 60 min values being slightly less. Between group comparisons showed there to be no significant differences in [Hla] values between the TP and the AB subjects in either climate.

(f) Sweat rate (These results are shown in Table III)
The AB subjects recorded slightly greater sweat rates in both climates than the TP, but their respective values were not significantly different in either climate.

Discussion

Fitness
The $\dot{V}O_2$ max values measured here in the TP are very similar to those reported by Davis and Shephard[17] who also tested paraplegic subjects. The TP and AB subjects' $\dot{V}O_2$ max values are higher than those reported by Van Loan *et al*,[18] although their subject groups are likely to have included a wide range of fitness levels. In contrast, the TP $\dot{V}O_2$ max values are lower than those reported by Gass *et al*[9] for similarly well trained paraplegics. However, their subjects were tested in wheelchairs on a motor driven treadmill and generally this mode of exercise produces greater $\dot{V}O_2$ max values than arm crank ergometry.[7] The TP and AB

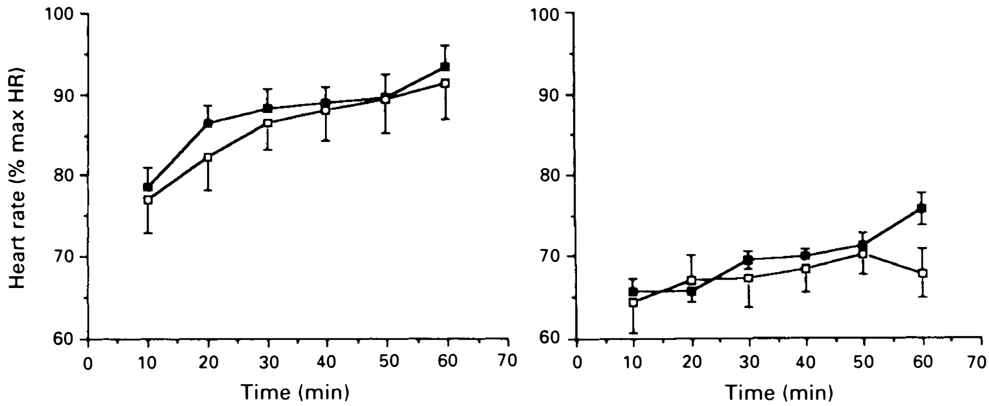

Figure 3 Mean (± SE) heart rate responses of trained paraplegics (TP: ■) and able bodied (AB: □) subjects during submaximal exercise in hot (left panel) and cool (right panel) climates.
Note: Hot climate: Both groups recorded a significant linear ($p < 0.01$) and quadratic ($p < 0.01$) change over the exercise period. There were no significant interactions between the TP and AB subjects.
Cool climate: Both groups recorded a significant linear ($p < 0.01$) increase over the exercise period. There were no significant interactions between the TP and AB subjects.

Table III Blood lactate concentrations [Hla] and sweat rates recorded for trained paraplegics and able bodied subjects during submaximal arm crank ergometer exercise in hot and cool climates

		Trained paraplegics	Able bodied subjects
[Hla] mmol l^{-1}			
Pre-Ex	Hot	1.1 ± 0.2	0.8 ± 0.1
	Cool	1.0 ± 0.1	0.8 ± 0.1
30 mins	Hot	3.6 ± 0.5	4.1 ± 0.7
	Cool	2.7 ± 0.3	3.3 ± 0.6
60 min	Hot	2.9 ± 0.5	3.4 ± 0.5
	Cool	1.8 ± 0.3	1.9 ± 0.3
Sweat rate g h^{-1}	Hot	962 ± 17	1156 ± 113
	Cool	305 ± 36	396 ± 59

There were no significant differences between groups.
Values presented are $\bar{X}$ ± SEM.

subjects were similar in all physiological measures except $\dot{V}O_2$ max (1 min^{-1}). However, this difference was controlled for by having the subjects exercise at the same relative intensity (i.e. 55–60% $\dot{V}O_2$ max) during the prolonged submaximal exercise tests. The level of core temperature reached during exercise is proportional to the relative, not the absolute workload.[19]

Thermoregulatory responses
This study is believed to make a specific addition to the body of knowledge concerning the thermoregulation of paraplegics. The data collected here permit a comparison of the thermoregulatory abilities of TP and AB subjects performing arm ergometry exercise in both hot and cool conditions, which has not previously been made. Also, data on the thermoregulatory responses of paraplegics exercising in hot conditions has not been previously reported, and this has important implications for the safety of paraplegics performing prolonged exercise in hot and/or humid conditions.

There were few differences between the groups in their responses to the exercise in either hot or cool conditions. In the hot climate the TP recorded similar Tr, HR, [Hla] values and sweat rates to the AB subjects, with the only significant difference recorded being a greater $\Delta\bar{T}sk$ 0–60 min in the TP. Therefore, in general, the TP exhibited a sound thermoregulatory ability in the face of a moderate exercise load performed for 60 min in a hot climate. However, one TP completed only 35 min of exercise in the heat, at which point his HR and $\dot{V}O_2$ were approximately 96% and 78% of maximum respectively. This subject was also asthmatic, which may have contributed to his distress during this exercise period. He had no difficulty in completing 60 min of exercise in the cool conditions.

The $\bar{T}sk$ of the TP in the hot climate rose steadily throughout the exercise period, whereas, in contrast, the $\bar{T}sk$ of the AB subjects decreased over the final 30 min. A similar response was noted by Fitzgerald *et al*,[5] during submaximal wheelchair ergometry for 90 min in cool conditions. As a result, the $\Delta\bar{T}sk$ value (0–60 min) recorded in the present study was significantly greater in the TP than the AB subjects. The individual Tsk responses of the lower limb in the TP may explain these divergent findings. Gass *et al*[9] found that thigh and calf temperatures increased to a greater degree than arm and head temperatures in TP performing 80 min of continuous, moderate load exercise in cool conditions. Similar trends were found in the present study in the hot climate. The change (0–60 min) in sternum and arm temperatures were not significantly different between the two groups, but change in thigh and calf temperatures (4.74 ± 1.07 °C and 3.93 ± 0.60 °C respectively) for the TP were significantly greater ($p < 0.05$) than recorded for the AB subjects (2.63 ± 0.36 °C and 1.50 ± 0.32 °C).

These findings may be the result of blood pooling in the lower limbs in the TP due to poor muscle tone and venous return, which may in turn cause elevated thigh and calf temperatures. The spinal lesion level may be an important factor in this response. Gass *et al*[9] found large increases in calf temperature during exercise in cool conditions with three subjects with lesions at T12, while, in contrast, two subjects with lesions at T10 showed small decreases. They suggested that the pathway for vasodilatory activity in the lower limb could be located at or below T10. The TP in the present study all had lesions at or below T12, thereby providing support for the previous findings of Gass *et al*.[9] However, because none of the TP had lesion levels at or above T10, their suggested location of the vasodilatory pathway cannot be supported or rejected by the results of the present study. The difference in environmental temperature (i.e. cool versus hot) between these two studies may also have some bearing on the $\bar{T}sk$ responses, as a greater vasodilation stimulus would no doubt exist in hot, rather than cool, conditions. The wearing of tracksuit pants by all the subjects during the exercise sessions may also have affected the lower limb Tsk. The evaporation of sweat and convective heat exchange for the legs would have been restricted by the wearing of the pants, however this would apply to both groups of subjects, and as there were no significant differences in sweat rate between the TP and AB subjects, blood pooling in the lower limbs of the TP may be the most likely explanation for the differences noted in $\Delta\bar{T}sk$.

The ΔTr values recorded by the TP during exercise in the heat were almost exactly the same as for the AB subjects (TP: $0.65 \pm 0.12\,°C$ and AB: $0.70 \pm 0.15\,°C$) and their final Tr of approximately 37.7 °C and sweat rate of almost $1000\,g\,hr^{-1}$ suggests that they were comfortably able to withstand the challenge to thermoregulation presented by the exercise load and the climate. While these results are a promising indication of the ability of TP to thermoregulate effectively during exercise in the heat, cardiovascular data (stroke volume and cardiac output) should be collected to investigate whether any changes in central blood volume may compromise the ability to continue exercise under these conditions.

Two other factors relevant for consideration when assessing these responses are the mode of exercise and the site of core temperature measurement. Arm ergometry involves a smaller exercising muscle mass than wheelchair propulsion, and it is possible that the arm crank exercise performed in this study did not produce enough metabolic heat to cause Tr to rise to higher and potentially more dangerous levels. Gass *et al*[9] recorded similar rises to Tr (to those found here) in TP who performed 80 min of wheelchair exercise at 60–65% $\dot{V}O_2$ max in cool conditions. Given the additional heat stress imposed by the hot climate in this study, it is likely that a greater magnitude of rise in core temperature would be experienced by paraplegics exercising in their wheelchairs. How effectively they could thermoregulate when performing this mode of exercise for a prolonged period in a hot climate is a topic worthy of investigation.

Gass *et al*[9] have also shown that esophageal (Tes) temperature rose significantly faster than Tr in TP performing prolonged submaximal wheelchair propulsion in cool conditions. Such a difference has not been found in AB subjects.[20] Poor venous return from the lower limbs in paraplegics could result in less warm blood passing via the rectal cavity and conceivably produce divergent Tes and Tr responses. The ability to redirect blood flow from the splanchnic area to more active areas during exercise would also be an important factor. This will depend on the lesion level, which will determine the amount of intact sympathetic innervation. Therefore, it is possible that the measurement of Tes values may have produced a different response to that exhibited in Tr values by the TP during the exercise sessions. Gass *et al*[9] have also suggested that, apart from lesion level, factors such as fitness level, wheelchair design and seat position may alter venous return dynamics in subjects with similar lesion levels, and thereby contribute to Tes-Tr differences. The simultaneous measurement of Tes and Tr values in paraplegics exercising in hot conditions would provide further evidence of the thermoregulatory abilities of these subjects and may show differences not found here between TP and AB subjects.

In the cool climate, as might be expected, both the TP and AB subjects experienced little difficulty in completing the 60 min exercise period. Both groups were able to reach a plateau in Tr response after approximately 30 min of exercise and recorded decreases in $\bar{T}sk$ across the exercise period, suggesting that, under these exercise and environmental conditions, the TP were capable of effective evaporative cooling. Gass and colleagues[8,9] have previously shown that paraplegic men can perform prolonged submaximal exercise in cool conditions without experiencing marked thermoregulatory strain.

In conclusion, for the exercise and climatic conditions used in this study, it was found that TP can successfully regulate their body temperatures during prolonged submaximal exercise in hot and cool climates at a level comparable to that of AB subjects performing identical exercise. Whether this is also the case during wheelchair propulsion at higher intensities of exercise should be investigated. Future research might also investigate the Tsk responses of paraplegics exercising in hot conditions more closely, as lower limb surface temperatures may be increased considerably due to venous pooling.

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