ORIGINAL ARTICLE

Aerobic capacity and peak power output of elite quadriplegic games players

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Background: Participation in wheelchair sports such as tennis and rugby enables people with quadriplegia to compete both individually and as a team at the highest level. Both sports are dominated by frequent, intermittent, short term power demands superimposed on a background of aerobic activity.
Objective: To gain physiological profiles of highly trained British quadriplegic athletes, and to examine the relation between aerobic and sprint capacity.
Methods: Eight male quadriplegic athletes performed an arm crank exercise using an ergometer fitted with a Schoberer Rad Messtechnik (SRM) powermeter. The sprint test consisted of three maximum-effort sprints of five seconds duration against a resistance of 2%, 3%, and 4% of body mass. The highest power output obtained was recorded (PPO). Peak oxygen consumption ($\dot{V}O_{2peak}$), peak heart rate (HR_{peak}), and maximal power output (PO_{aer}) were determined.
Results: Mean PO_{aer} was 67.7 (16.2) W, mean $\dot{V}O_{2peak}$ was 0.96 (0.17) litres/min, and HR_{peak} was 134 (19) beats/min for the group. There was high variability among subjects. Peak power over the five second sprint for the group was 220 (62) W. There was a significant correlation between $\dot{V}O_{2peak}$ (litres/min) and PO_{aer} (W) ($r = 0.74$, $p<0.05$).
Conclusions: These British quadriplegic athletes have relatively high aerobic fitness when compared with the available literature. Moreover, the anaerobic capacity of these athletes appeared to be relatively high compared with paraplegic participants.

In recent years competitive opportunities for both wheelchair rugby and quadriplegic tennis have gained increasing acceptance and popularity at Paralympic level. Wheelchair rugby made an official debut at the 2000 Paralympics, and the quadriplegic division was introduced to the tennis programme at the 2004 Paralympics. Both these sports allow quadriplegics to compete at the highest level, and they are both characterised by an intermittent activity profile with periods of explosive effort superimposed on a background of aerobic activity.

Aerobic and anaerobic capacities have been reported for wheelchair dependent sportspersons using various protocols and ergometers.[1–9] The limited amount of knowledge on elite quadriplegic wheelchair athletes in comparison with paraplegic athletes may primarily be due to population availability. However, with the recent influx of competitors with quadriplegia, it is paramount that this information becomes available so that scientifically based guidelines for sports training can develop.

In addition to the traditional measurement of peak oxygen consumption, peak external power output has been identified as a key indicator of performance.[9] It is of particular interest to note that differences in mechanical efficiency exist between arm crank and wheelchair propulsion. As a consequence, power output during arm crank ergometry has been found to be higher than that obtained during wheelchair ergometry for both paraplegic and quadriplegic subjects.[10 11] Obviously it is important to link the assessment modality to the type of locomotion used by the spinal cord injured persons for training.[5 10] However, standardisation of equipment and exercise arm crank testing procedures is of prime importance. Therefore initial assessments using arm crank ergometry will help to control for the different levels of efficiency and technique strategies that are apparent during wheelchair propulsion.[5 12] The relevance is to generate a functionality related database of performance, with power output being one of the outcome measures.[9]

The main objective of this study was to gain a physiological profile using arm crank ergometry where the Schoberer Rad Messtechnik (SRM) Training System (science model powermeter, power control, and computer software) could be used. This system is capable of recording power output directly at the crank arm, when power is rapidly changing over shorter durations of time such as five seconds, which is representative of these sports. Consequently, the purpose of this study was to gain a descriptive analysis of both aerobic and sprint capacity of highly trained British quadriplegic athletes. The secondary purpose was to evaluate the relation between aerobic capacity and indices of sprint performance that could be measured by unique methods using a SRM crank.

METHODS

Participants

Eight male wheelchair athletes volunteered to participate in the study after being informed of the purpose and procedures, which were approved by the university ethics committee. Subjects were tetraplegic athletes (C5/6 to C6/7; two with incomplete lesions); all were able to use their arms during wheelchair propulsion but had impaired use of their hands. All subjects trained and competed regularly in wheelchair tennis (n = 4) and rugby (n = 4) at either national or international level.

After medical screening by a doctor, all subjects refrained from vigorous exercise, caffeine, and alcohol for 24 hours before reporting to the laboratory. Before the testing protocols, body mass was measured to the nearest 0.1 kg using a seated balance scale (300 series; Marsden, London,

Abbreviations: HR, heart rate; PO_{aer}, peak aerobic power output; PPO, peak power output; $\dot{V}O_{2peak}$, peak oxygen uptake

Table 1 Disability and anthropometric characteristics of the quadriplegic athletes

Subject	Age (years)	Body mass (kg)	Lesion level	Paralympic sport	SFSS (mm)
1	34	75.1	C6/7	Tennis	69.1
2	30	72.0	C6 Inc	Tennis	61.0
3	24	69.0	C5/6 Inc	Tennis	57.8
4	32	57.0	C6/7	Tennis	62.6
5	30	72.9	C6	Rugby	37.1
6	24	72.2	C6/7	Rugby	44.9
7	31	61.4	C6/7	Rugby	–*
8	30	93.5	C6	Rugby	71.6
Mean	29	71.6			57.7
SD	4	10.8			11.6
Min	24	57.0			37.1
Max	34	93.5			71.6

SSFS, sum of four skinfold sites; Inc, incomplete lesion.
*Not available because of technical difficulties.

UK), and sum of four skinfolds (Harpenden Instruments, Marsden, UK) was measured as described by Durnin and Womersley.[13] All subjects were aged 25–35 and had a mean (SD) body mass of 71.6 (10.8) kg.

Instrumentation

Exercise testing was performed on a modified cycle ergometer (Monark, Ergomedic 620, Varberg, Sweden) adapted for upper body exercise so that athletes could remain in their everyday wheelchairs for testing. The seat height of these chairs ensured that the scapula-humeral joint and the crank pedal axle were at the same level. As the subjects had impaired hand function, assistance in gripping the hand cranks was provided through taping where necessary. Power measuring cranks (SRM, Welldorf, Germany) were fitted to the ergometer to record power output continuously at a sampling rate of 0.5 Hz. The SRM system was calibrated immediately before each experimental protocol in accordance with the manufacturer's operating instructions. Data were stored on an SRM power controller III, and then downloaded on to a PC. All subjects were familiar with arm crank exercise as part of their regular training regimen.

Experimental procedure

The participants were asked to void their bladder before the exercise tests. Before the main testing protocols, a standardised seven minute warm up was completed. This involved five minutes of arm cranking at 60 rev/min (30 W), followed by a further two minutes of intermittent exercise that consisted of 30 seconds passive rest then arm cranking at 70 rev/min for 30 seconds (35 W).

Sprint power

To ascertain peak power output (PPO), which may vary depending on limb length,[14] subjects completed a force-velocity test consisting of three maximum-effort sprints of five seconds duration. Each sprint was interspersed by five minutes of self selected active recovery on the unloaded ergometer. The initial sprint resistance was 2% of body mass, and athletes completed two more sprints that each increased in resistance by 1% of body mass. Verbal encouragement was given throughout the test, and the resistance that yielded the highest PPO was reported. This protocol has been used previously for quadriplegic athletes[15] and was adapted from force-velocity arm crank testing of able bodied volleyball players which relied on mathematical conversion of velocity and force data into PPO.[14] In the present investigation, the SRM system gathered power data directly so mathematical conversions were not necessary to gain PPO.

Aerobic power

After a 90 minute period of chaperoned rest, the second test required participants to complete a continuous incremental exercise test to determine peak oxygen uptake ($\dot{V}O_{2peak}$) and peak aerobic power output (PO_{aer}). This test involved 5 W increments of workload every two minutes at a cadence of 60 rev/min. The initial power output ranged from 25 to 50 W on the basis of each participant's performance in the previous sprints. Ratings of perceived exertion were collected during the warm up. The starting intensity was 60% PO_{aer}, and the test was designed to prevent local fatigue, by ensuring that the test duration was no longer than 14 minutes for each participant. During the last minute of each stage, a mouthpiece with a two way value connected to low resistance wide bore tubing allowed the collection of expired air in 150 litre Douglas bags. Samples were subsequently analysed for oxygen and carbon dioxide content (Servomex, Crowborough, Sussex, UK) and expired volume (Harvard Dry Gas Meter; Scientific and Research Instruments Ltd, Folkestone, Kent, UK). Heart rate (HR) was continually monitored (Polar Sports Tester; Polar Electro Oy, Kempele, Finland). A test terminated when, because of exhaustion, the participant could no longer maintain 60 rev/min despite verbal encouragement. PO_{aer} was defined as the highest PO that the participant could exert during the final minute.

Data analysis

Descriptive statistics were used and presented as mean (SD). As suggested by Janssen *et al*,[16] the PPO was expressed per kilogram body mass to minimise the influence of body mass during interpretation of the anaerobic capacity data. To establish the associations among indicators for aerobic capacity and indicators of sprint capacity, two tailed Pearson correlations were calculated. The level of significance deemed acceptable was $p<0.05$.

RESULTS

Table 1 presents the disability and anthropometric characteristics of the athletes. All but two of the quadriplegic athletes had a complete lesion. The group was relatively heterogeneous with respect to body mass and the sum of four skinfold sites: mean (SD) values were 71.6 (10.8) kg and 57.7 (11.6) mm (range 37.1–71.6 mm) respectively. The lowest was found in the C6/7 rugby athlete.

Sprint power relative to body weight varied between 1.84 and 4.26 W/kg (table 2). The highest value, 4.26 W/kg (307 W), was achieved by one of the tennis players, who displayed the greatest level of functional ability because of having an incomplete C6 level lesion (athlete 2). Mean peak power over the five second sprint for the group was 220 (62) W (table 2).

Table 2 The physiological data obtained from the sprint and peak aerobic arm ergometry tests

		Sprint test		Aerobic capacity			
Subject	Body mass (kg)	PPO (W)	PPO (W/kg)	$\dot{V}O_{2peak}$ (litres/min)	PO_{aer} (W)	PO_{aer} (W/kg)	HR_{peak} (beats/min)
1	75.1	216	2.88	1.08	85.0	1.13	127
2	72.0	307	4.26	1.18	82.6	1.15	168
3	69.0	194	2.81	1.20	66.0	0.96	123
4	57.0	129	2.26	0.66	40.1	0.70	115
5	72.9	134	1.84	0.83	66.5	0.91	153
6	72.2	233	3.23	0.86	49.9	0.69	146
7	61.4	252	4.10	0.90	68.4	1.11	121
8	93.5	294	3.14	0.97	83.3	0.89	122
Mean	71.6	220	3.07	0.96	67.7	0.94	134
SD	10.8	62	0.83	0.17	16.2	0.18	19

PPO, Peak power output during the five second sprint test; $\dot{V}O_{2peak}$, peak oxygen uptake; PO_{aer}, peak aerobic power output.

Mean PO_{aer} was 67.7 (16.2) W and mean $\dot{V}O_{2peak}$ was 0.96 (0.17) litres/min, both expressing up to 53% variation (table 2). HR_{peak} was 134 (19) beats/min for the group; this was also highly variable. For athlete 2 (C6 Inc), HR_{peak} appeared to be associated with the incompleteness of lesion level, as a peak value of 168 beats/min was achieved, whereas the other participant with an incomplete lesion only recorded a HR_{peak} of 123 beats/min.

Table 3 shows the association between sprint power and aerobic capacity. A significant correlation was observed between $\dot{V}O_{2peak}$ (litres/min) and PO_{aer} (W) ($r = 0.74$, $p<0.05$; fig 1). No clear association was seen between $\dot{V}O_{2peak}$ (litres/min) and PPO (W) or between PO_{aer} (W/kg) and PPO (W/kg) ($r \geqslant 0.56$, NS).

DISCUSSION

It has often been suggested that one of the difficulties of evaluating the physical work capacity of Paralympic athletes is that they usually represent a heterogeneous group.[4 7 17] The data obtained from the present study provide a unique opportunity to establish the physiological profiles of a group of highly trained quadriplegic athletes with games playing backgrounds. To our knowledge, no previously published studies have directly sought to examine the power output profiles of spinal cord injured athletes using a SRM arm cranking system. Hence, it is recognised that, in the first instance, the research was not designed to replicate wheelchair propulsion conditions.

It has been substantiated that aerobic power is related to the level of lesion.[15] Hence, the higher the spinal cord lesion or completeness of lesion the more limited $\dot{V}O_{2peak}$ tends to be. The mean $\dot{V}O_{2peak}$ value of 0.96 litre/min is similar to those reported for track athletes,[2 9] but considerably less than the $\dot{V}O_{2peak}$ measured by Campbell *et al*[18] (1.28 (0.16) litres/min; n = 3). However, it is important to note that, for these studies, $\dot{V}O_{2peak}$ was derived from wheelchair propulsion protocols as opposed to an arm crank exercise. Furthermore, the latter study involved wheelchair racers.[18] Nevertheless, this comparison showed that these athletes were well conditioned, but may not be at the level of endurance based athletes previously reported in the United Kingdom.[18] The mean aerobic power of 67.7 W is comparable to the work of Woude *et al*,[9] and suggests that the quadriplegics showed a good level of muscular/cardiovascular function. As expected, the correlation between $\dot{V}O_{2peak}$ and PO_{aer} was relatively high, which indicates a consistent relation between these indices. Observation during training of the games players showed that they participated in drills that involved short sprints, chair agility drills, hand cycling, and general pushing. This type of cross training has enabled them to display a good level of aerobic fitness and muscular endurance. However, slight improvements could be made to improve aerobic capacity to the levels observed in long distance track athletes,[18] although muscular endurance and anaerobic capacity must not be compromised. At a general anthropometric level, the average body mass and sum of four skinfolds compare well with those of trained male wheelchair basketball players.[4]

Table 3 Correlation matrix of key indicators of aerobic capacity and sprint capacity

	$\dot{V}O_{2peak}$ (litres/min)	PO_{aer} (W/kg)
Aerobic		
PO_{aer} (W)	0.72*	–
Sprint capacity		
PPO (W)	0.56	–
PPO (W/kg)	–	0.79*

PO_{aer}, Peak aerobic power output; $\dot{V}O_{2peak}$, peak oxygen uptake; PPO, peak power output during the five second sprint test.
*$p<0.05$.

The group's mean peak HR of 134 (19) beats/min with a range of 115–168 beats/min supported the fact that the HR of two of the participants was not impaired by abnormal autonomic cardiac regulation because of the incomplete nature of the spinal cord injury.[19] The low peak HRs are the result of the well documented evidence suggesting a lack of sympathetic innervation to the heart for lesions at the cervical level.[1 9 18] The large variability in $\dot{V}O_{2peak}$ and HR clearly appeared to be related to the degree of completeness of the spinal cord lesion.

For games players, the improvement in anaerobic power is particularly important for the low point rugby players, who lack wheelchair skill because of their trunk instability. Any improvement in their anaerobic power could be significant on court. The mean PPO was found to be 220 (62)W, but it is difficult to compare this with previous anaerobic indices of spinal cord injured athletes because of the inconsistency in

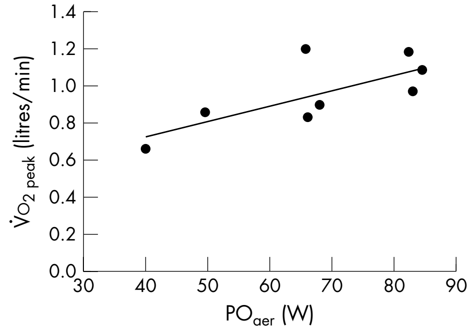

Figure 1 Relation between maximal power output (PO_{aer}) and peak oxygen consumption ($\dot{V}O_{2peak}$) (n = 8).

What is already known on this topic

- The relations between anaerobic and aerobic indices of performance in wheelchair athletes have been reported
- Competitive opportunities for quadriplegic participants are increasing. Few studies have examined the physiological responses of quadriplegic participants, and there is no database for British competitors

What this study adds

- This study provides a physiological profile of elite quadriplegic games players, using a unique method, the SRM power crank, during arm crank exercise
- The British athletes studied have relatively high anaerobic profiles compared with paraplegic participants. The relation between aerobic and anaerobic indices of performance helped to quantify training status

the methods used.[5] Hutlzer *et al*[6] has reported values of 338 W for high level paraplegics during arm cranking, and constructed a PPO reference table with a range of 279–382 W for average performance levels. Given that this range was derived from data on paraplegics not quadriplegics suggests that the group of quadriplegics in our study are above average in terms of anaerobic capacity. Although we are unable to make direct comparisons, these values do provide us with useful information for establishing initial performance levels. Furthermore, the relation between aerobic and anaerobic indices can be explored. A negative correlation of aerobic and anaerobic indices would be expected if the athletes specialised in the cross training regimens previously mentioned. A fair and non-significant positive relation was found between $\dot{V}O_{2peak}$ (litres/min) and PPO (W) ($r = 0.56$). Moreover, a positive and significant correlation was found between the relative aerobic capacity (PO_{aer}; W/kg) and PO_{aer} (W/kg) ($r = 0.79$), showing that there was no evidence of specialist endurance or power based training. These results support the results of a study of wheelchair basketball players also performing arm crank tests.[20] However, they differ from the significant relation found between aerobic and anaerobic indices during wheelchair exercise.[2 9 16] More research is needed to substantiate these findings, as the lack of significant relation may be due to the continued small sample size or indeed the exercise test modality: arm cranking versus wheelchair propulsion.

In summary, the group of quadriplegics in this study exhibited physiological responses representative of a well trained population. The use of the SRM system combined with arm cranking allowed a standardised assessment of both aerobic and anaerobic indices of performance without interference from ineffective technique strategies that may have been displayed through wheelchair exercise protocols. Although the study focused on quadriplegic athletes, high variability among the athletes in terms of aerobic capacity was still evident, which appeared to be indicative of the impairment—that is, completeness of the lesion level. The benefits of specific training and cross training in wheelchair games sports need to be explored.

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COMMENTARY

This is an interesting paper with relevant information on athletes with a quadriplegic level lesion. As the number of elite athletes with a quadriplegic level lesion is limited, the study group is unfortunately small and of course heterogeneous.

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