TREADMILL PERFORMANCE AND SELECTED PHYSIOLOGICAL CHARACTERISTICS OF WHEELCHAIR ATHLETES

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ABSTRACT

The purpose of this study was to examine selected physiological characteristics and pushing performance over a distance of five kilometres (5 km) in twelve wheelchair athletes (10 paraplegics and 2 tetraplegics). The physiological tests and 5 km wheelchair time trials were performed on a motorised treadmill adapted for use by wheelchairs. The maximum oxygen uptake ($\dot{V}O_2$ max) and % $\dot{V}O_2$ max utilised at a fixed speed equivalent to a blood lactate concentration of 4 mmol.l⁻¹, identified as being of importance in successful able-bodied endurance performance, were also found to correlate highly with 5 km performance in wheelchair athletes. Low correlations were found between performance and mean % $\dot{V}O_2$ max utilised over the whole distance and between performance and oxygen uptake at a standard speed. The results also showed that the tetraplegics had lower physiological reserves than the paraplegics, with a much reduced maximum heart rate and ventilation. The findings indicate that a combination of physiological characteristics influence pushing performance in wheelchair athletes.

INTRODUCTION

The last decade has seen a sharp increase in the number of tetraplegic and paraplegic athletes participating in wheelchair sports. This has resulted in an improvement in the standards of performance (Steadward and Walsh, 1986). This increase in participation has also stimulated research on the physiological responses of wheelchair athletes to exercise. The results from some of this work show that athletes with spinal cord injuries generally have a lower $\dot{V}O_2$ max for arm exercise than able-bodied athletes (Bar-Or and Zwiren, 1975; Glaser et al, 1980). This has been attributed, in part, to the reduced functional muscle mass available for exercise, and a suggestion supported by the common finding that the lower the level of the lesion the higher the value of $\dot{V}O_2$ max attained (Gass and Camp, 1979; Coutts et al, 1983; Wicks et al, 1983). In addition to having the least functional muscle mass tetraplegics have the greatest loss of the autonomic nervous system (Glaser et al, 1980). These facts help to explain the markedly lower maximum heart rate and ventilation in this group compared with paraplegics (Ekblom and Lundberg, 1968; Knuttson et al, 1973; Gass et al, 1980).

The increased knowledge from research on the wheelchair athlete has resulted in an improvement in the training techniques (Corcoran et al, 1980). These, in turn, have contributed to the improvements seen in performance. Although more information is now available on the physiological responses of wheelchair athletes to exercise, little has been done to relate these responses to actual performance. In able-bodied athletes several physiological factors have been identified as being highly correlated with endurance performance, notably:— a high $\dot{V}O_2$ max (Saltin and Åstrand, 1967; Davies and Thompson, 1979); the ability to utilise a high proportion of $\dot{V}O_2$ max for long periods of time (Costill et al, 1973; Davies and Thompson, 1979; Sjödín and Schèle, 1982); running economy (Conley and Krahenbuhl, 1980; Sjödín and Schèle, 1982); and the ability to run at high speeds with low blood lactate concentrations (Sjödín and Jacobs, 1981; Kumagi et al, 1982). It also appears that distance runners maintain a

running pace which allows the utilisation of the largest % $\dot{V}O_2$ max which just avoids the exponential rise in blood lactate (Farrell et al, 1979). The purpose of the present study was to examine the relationship between some of these physiological characteristics and 5 km treadmill performance time for a group of wheelchair athletes.

METHOD

Twelve wheelchair athletes, ten paraplegics and 2 tetraplegics, volunteered to participate in this study. They all trained regularly and participated in a wide range of sporting activities, with five of the athletes competing at international level. The subjects were asked to perform two tests; (a) an incremental exercise test, and (b) a 5 km treadmill time trial. Both tests were performed on a motorised treadmill (Woodway model ELGZ) which was adapted for use by wheelchairs as shown in Fig. 1. The subject's own chair was attached to the slider mechanism at position A, which allowed freedom of movement of the wheelchair forwards and backwards but restricted sideways movements. A safety backstop did not permit the wheelchair to travel backwards off the treadmill belt, should the athlete stop pushing. Each subject was fully familiarised with wheelchair pushing on the treadmill and also the

Fig. 1: The motorised treadmill wheelchair system.

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operation of the self-selection speed control which was used by the subjects to alter the treadmill belt speed during the 5 km test. The ability to push comfortably with the expired air collection apparatus in place was also checked before measurements were made.

A rolling start was employed for the 5 km time trial with the treadmill set at a submaximal speed of 3.5 m.s^{-1} . Once the test had started the subjects were able to adjust the treadmill speed using the self-select switch and were encouraged to cover the 5 km as quickly as possible. A single, incremental exercise test was adopted to determine the relationship between oxygen uptake, blood lactate and pushing speed for each individual. The test required each subject to push at each of four submaximal speeds for 4 minutes at each speed. At the conclusion of the fourth submaximal speed the athletes continued to push at a near maximal speed until voluntary exhaustion, for determination of $\dot{V}\text{O}_2 \text{ max}$. The third treadmill speed, which was used as the reference speed, was determined for each athlete from the average pushing speed achieved between minutes 9 and 12 of the 5 km time trial. The first two speeds were 1 m.s^{-1} and 0.5 m.s^{-1} , less than this reference speed. The fourth speed was the maximum speed achieved for 3-4 minutes during the 5 km time trial, with the final speed being a further $0.2\text{-}0.5 \text{ m.s}^{-1}$ faster.

During the last minute of each speed expired air was collected in Douglas Bags via a low resistance respiratory valve (Jakeman and Davies, 1979). At the end of each speed the subject stopped pushing and a thumbprick blood sample was taken for determination of blood lactate concentration. Each of the duplicate $25\mu\text{l}$ blood samples was deproteinised in $250\mu\text{l}$ of 2.5% perchloric acid, centrifuged and stored at -20°C . The subject recommenced pushing after one minute recovery, except after the fourth speed where the subject started pushing at the new speed as soon as the blood sample had been taken. The subject then pushed at this final speed, indicating when only one more minute of exercise could be achieved. Expired air was collected during this final minute and the test was then terminated. Throughout the tests heart rates were continuously monitored (Rigel Cardiac Memory Monitor 302). Expired air samples were analysed using a mass spectrometer (Centronic MGA200). The blood lactate concentrations were determined using a modification of Olsen's fluorometric procedure (Maughan, 1982).

Individual regression equations were calculated for the relationship between oxygen consumption and pushing speed and the oxygen cost of racing was estimated from these equations. In order to examine the inter-individual differences in pushing economy, the oxygen cost of pushing at a fixed speed of 4 m.s^{-1} was also estimated from the regression equation. The speeds equivalent to a blood lactate concentration of 4 mmol.l^{-1} were derived from the individual relationships between blood lactate concentration and pushing speed.

RESULTS

The physiological characteristics of the 12 subjects are shown in Table I. The value of $\dot{V}\text{O}_2$ for the whole group was $1.82 \pm 0.47 \text{ l.min}^{-1}$ (mean $\pm$ S.D.) with all the values for the paraplegics being greater than those obtained for the two tetraplegics. Maximum values of ventilation and heart rate were lower for the tetraplegics than the paraplegics, with the tetraplegics exhibiting a plateau in ventilation at approximately 90% of maximum pushing speed (Fig. 2).

TABLE I

Levels of spinal lesion, age and physiological characteristics of the wheelchair athletes.

Subject	Lesion Level	Age years	$\dot{V}\text{O}_2 \text{ max}$ l.min^{-1}	$\dot{V}_E \text{ max}$ l.min^{-1}	H.R. max b.min^{-1}
Tetraplegics					
a	C7	30	1.08	33.2	108
b	C7	35	1.21	35.8	129
Paraplegics					
c	T4	26	1.86	64.0	184
d	T4	24	1.71	56.8	206
e	T11/T12	22	2.30	69.2	202
f	T11/T12	15	1.50	69.8	196
g	L1	18	2.41	104.7	210
h	L1	37	1.37	65.7	186
i	L1	25	2.47	67.0	162
j	L1	31	1.78	56.5	180
k	L1/L2	15	2.18	54.2	205
l	L1/L2	22	1.91	60.0	198
	mean	24	1.95	66.8	193
	$\pm$ S.D.	7	0.38	14.4	15

Fig. 2: The relationship between ventilation and pushing speed for the paraplegic group (mean $\pm$ S.D.) and the two tetraplegics.

Fig. 3: The relationship between oxygen uptake and pushing speed for the whole group (mean $\pm$ S.D., $n = 12$).

TABLE II
Pushing time and pace, estimated oxygen cost and estimated % $\dot{V}O_2$ max at 5 km pace at 4 m.s for the two tetraplegics and the paraplegic group (mean $\pm$ S.D.).

		Trial Time (mins)	Trial Pace (m.s ⁻¹)	Est. $\dot{V}O_2$ (l.min ⁻¹)	Est. % $\dot{V}O_2$ max (%)	Est. % $\dot{V}O_2$ at 4 m.s ⁻¹	Est. % $\dot{V}O_2$ max at 4 m.s ⁻¹
Tetraplegics	a	20.57	4.07	1.03	95.4	1.01	92.3
	b	24.00	3.47	1.03	85.1	1.13	92.6
Paraplegics		20.33	4.20	1.50	76.3	1.37	71.0
		± 2.93	± 0.69	± 0.41	± 11.1	± 0.43	± 20.0

The oxygen cost of wheelchair pushing on the treadmill is shown in Fig. 3. A correlation of 0.69 was found between oxygen uptake and pushing speed ($p < 0.05$). The performance results and estimated oxygen consumptions are shown in Table II. The estimated mean % $\dot{V}O_2$ max utilised during the 5 km test, for all 12 athletes, was 79% (range 61% to 95%). The mean pushing speed equivalent to a blood lactate concentration of 4 mmol.l⁻¹ was found to be 4.23 ± 0.97 m.s⁻¹. This speed was not significantly different from the average speed (4.13 ± 0.65 m.s⁻¹) which the subjects achieved during the 5 km test (V5 km). The heart rate responses were significantly different between the groups ($p < 0.001$) with the tetraplegics' heart rates markedly lower throughout the test (Fig. 4). All the athletes, however, were working at between 80 and 90% of their respective maximum heart rates.

Fig. 4: Heart rate responses during the treadmill 5 km push for the paraplegic group (mean $\pm$ S.D.) and the two tetraplegics.

DISCUSSION

The mean $\dot{V}O_2$ max value of 1.82 l.min⁻¹ for all the athletes is lower than the values reported for able-bodied athletes performing similar arm exercise (Bar-Or and Zwiren, 1975; Glaser et al, 1980). This may be explained, in part, by the reduced functional muscle mass available to the paraplegic and tetraplegic athletes. The mean values of $\dot{V}O_2$ max and maximum heart rate for the paraplegic subjects are, however, comparable with those previously found in wheelchair athletes (Gass and Camp, 1979; Gass et al, 1980; Coutts et al, 1983; Wicks et al, 1983). The two tetraplegics in the group had lower values of $\dot{V}O_2$ max, maximum ventilation and maximum heart rate than the paraplegic athletes. However, their values were also similar to those reported in the literature for similar levels of spinal lesion (Ekblom and Lundberg, 1968; Gass and Camp, 1979; Coutts et al, 1983).

The difference in the heart rate response between the paraplegic and tetraplegic athletes during the 5 km test is

due to the lack of sympathetic innervation to the heart in the tetraplegics. In the tetraplegic athlete the maximum heart rate is determined by the sinoatrial rhythm (Smith et al, 1976) and, therefore, the maximum heart rates would be expected to be between 100-125 beats min⁻¹ (Knuttsen et al, 1973). The two tetraplegics also had a lower maximal ventilation than the paraplegics (Table II). This is probably due to the reduced sympathetic innervation of the intercostal and abdominal muscles which are required for ventilation. Although ventilation has not been reported to limit $\dot{V}O_2$ max or performance in tetraplegics, ventilation did not increase with increasing intensity of effort in the two tetraplegics above approximately 90% of $\dot{V}O_2$ max. This may indicate that ventilation is limiting maximum oxygen uptake. The paraplegic athletes, however, showed the exponential relationship between ventilation and intensity of exercise that is invariably found for able-bodied athletes.

The range of measured values of $\dot{V}O_2$ max and the 5 km performance times for the wheelchair athletes were wide. A correlation coefficient of 0.61 ($p < 0.05$) was obtained between $\dot{V}O_2$ max was correlated with V5 km, thus indicating the importance of $\dot{V}O_2$ max for performance. This relationship has been well established in running (Davies and Thompson, 1979). When only the highly trained endurance athletes were considered the correlation between $\dot{V}O_2$ max and V5 km was increased to 0.77. It should be noted, however, that these athletes used racing wheelchairs on the treadmill which may have been the factor influencing the correlation value. As only 37-59% of the variance is accounted for in these correlations, there are obviously other factors, such as wheelchair design, that contribute to performance. Running economy has been described as an "essential attribute to running success" (Conley and Krahenbuhl, 1980). In the present study the pushing economy of the athletes, defined as the oxygen cost of pushing at 4 m.s⁻¹, was correlated with V5 km. The low value of 0.39 was obtained for the correlation coefficient, indicating that pushing economy alone is not a major factor influencing performance. Pushing economy may, however, moderate the effect of $\dot{V}O_2$ max on performance.

Costill et al (1973) suggested that the percentage of maximum oxygen uptake utilised at a given speed may be a more important physiological characteristic influencing performance than running economy, and presumably pushing economy, per se. The ability to sustain a high percentage of one's $\dot{V}O_2$ max is, therefore, important in endurance events. In the present study a high correlation ($r = -0.84$, $p < 0.05$) was found between % $\dot{V}O_2$ max utilised at 4 m.s⁻¹ and 5 km performance times. The estimated mean % $\dot{V}O_2$ max sustained by the athletes during the 5 km push was 79% ($\pm 13.2\%$). This value is similar to that reported by Williams and Nute (1983) for recreational runners during a half marathon, but is somewhat lower

than the value of around 87% $\dot{V}O_2$ max reported for a 5 km time trial (Ramsbottom et al, 1987). Although this ability is important to the individual, it should not be inferred that the mean % $\dot{V}O_2$ max utilised over the performance distance can be used to account for performance differences in the whole group ($r = 0.08$).

In running studies the speed at which the onset of the accumulation of blood lactate occurs has been found to be an important indicator of performance (Farrell et al, 1979; Sjödin and Jacobs, 1981; Kumagi et al, 1982). In the present study a high correlation ($r = 0.83$, $p < 0.05$) was found between the speed at which the blood lactate concentration reached 4 mmol.l⁻¹ and average pushing speed. This value was even higher ($r = 0.87$, $p < 0.05$) during the middle section of the test when the athletes were pushing at a fairly constant speed. This strong relationship between V4 mM and 5 km performance time has been reported for runners (Williams et al, 1985). It would appear that, as with running, the wheelchair athletes set a race pace which just avoids the exponential rise in blood lactate concentration.

In conclusion, the results of the present study suggest that the endurance performance of wheelchair athletes is influenced by several physiological characteristics and that the same methods that are used to characterise endurance runners can also be used to describe endurance wheelchair athletes. In addition it was clear that the tetraplegic athletes had lower functional capacities than the paraplegic athletes.

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