

Aerobic power of competitive paraplegic road racers

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The purpose of this study was to determine peak aerobic power and associated physiological responses in highly competitive spinal cord injured (SCI) paraplegic road racers. Seven (6 male and one female) active paraplegic (lesions T4–T12) road racers and 9 healthy untrained able-bodied males performed continuous graded arm crank ergometer tests to exhaustion for determinations of peak power output (PO), oxygen uptake ($\dot{V}O_2$), pulmonary ventilation (\dot{V}_E), heart rate (HR), and respiratory exchange ratio (RER). Compared to able-bodied subjects, male paraplegic road racers elicited significantly ($p \leq .05$) higher mean (\pm SD) peak levels of PO (141.6 ± 8.8 vs 111.4 ± 27.7 W), absolute $\dot{V}O_2$ ($2.72 \pm .52$ vs $2.22 \pm .38$ l/min), and $\dot{V}O_2$ per unit of body weight (43.06 ± 7.4 vs 30.33 ± 4.3 ml/kg/min). Although peak HR (180.3 ± 9.5 vs 173.2 ± 8.5 bpm) and \dot{V}_E (92.8 ± 17.2 vs 74.6 ± 20.3 l/min) tended to be higher for male paraplegic road racers than able-bodied subjects, the differences were not statistically significant. The female paraplegic road racer achieved the highest peak levels of PO (119 W) and $\dot{V}O_2$ (1.99 l/min; 38.0 ml/kg/min) reported to date for wheelchair-dependent women. These data suggest that intense physical training via wheelchair propulsion can markedly enhance upper body cardiovascular fitness in SCI paraplegics. However, the correlational analysis between 10 km time and peak $\dot{V}O_2$ was nonsignificant ($p > .05$) indicating that factors other than peak upper body aerobic power may influence wheelchair road racing performance.

Key words: aerobic fitness; oxygen uptake; paraplegia; spinal cord injured; upper body exercise; wheelchair athlete.

Introduction

One of the most widely recognized and publicized wheelchair sports events in recent years has been wheelchair road racing. The offering of prize money to successful performers in wheelchair road racing competition has prompted greater participation by wheelchair-dependent individuals in this particular sport, as well as the implementation of more specialized and rigorous training programs for wheelchair road racers.¹ To date, the largest contingent of wheelchair road racers is comprised of spinal cord injured (SCI) persons. Each of the aforementioned factors has contributed to the

generation of more research involving the physiological responses of SCI persons to upper extremity exercise.

Recent studies^{2–7} evaluating the peak upper body aerobic power of endurance-trained SCI athletes reveal the strong interest that the international research community has in this athletic population. However, these studies have generally involved either wheelchair track athletes^{2,3} or marathoners.^{5,6} To our knowledge, little attention has been given to well trained and highly competitive wheelchair road racers whose most common racing distance is 10 km. The purpose of this study was, therefore, to compare the aerobic power and associated peak physiological responses of active male SCI wheelchair road racers to healthy, but untrained, male able bodied subjects during maximal effort upper body

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exercise. In addition, since exercise performance data on women wheelchair athletes in general are scarce, the peak physiological responses to upper extremity exercise are also reported for one elite women SCI wheelchair road racer.

Subjects and methods

Six male SCI paraplegics and one woman SCI paraplegic with lesion levels ranging from T4 to T12 volunteered to participate in the study. Table I lists the personal characteristics of the SCI subjects. Each subject had suffered a traumatic spinal cord injury, and 5 were diagnosed as neurologically complete with respect to the loss of infralesional motor function. Each subject was an active participant in the 1987 Invacare Cup Road Racing Series which consisted of 7 races held throughout the United States over a 12-month period. Based on the International Stoke Mandeville Games Federation classification system,⁸ 3 subjects were class II athletes, 2 were class III athletes, and 2 were class IV athletes. At the time of data collection, this SCI group included the men and women wheelchair athletes with the current world record times for the 10 km distance. Nine healthy, moderately active, but aerobically untrained males volunteered to serve as a comparison group. Written informed consent and complete health and activity histories were

obtained from each subject prior to their participation in accordance with guidelines established by the University Human Subject Research Review Committee.

Testing occurred while the SCI athletes were in Phoenix, AZ for the sixth event of the 1987 Invacare Cup Road Racing Series. This race was to be 10 km in distance, but was cancelled due to rain. Thus, the elements of muscle fatigue or soreness that commonly occur after competitive wheelchair road races were not a factor during subsequent test sessions.

Each subject completed a continuous, progressive intensity arm crank ergometer (ACE) test to exhaustion. The ACE (Monark Rehab Trainer™, Monark-Crescent AB, Varberg, Sweden) was mounted on a metal frame similar to that previously described.⁹ Prior to exercise, the crank axle was positioned at mid sternum level, with slight elbow flexion when the arm was in the extended position. This allowed for standard placement of the ACE among subjects.

The test protocol required the subjects to maintain a target cadence of 70 rpm. A visual display of rpm was provided to each subject during all tests. The initial power output (PO) of 17 W was increased by 17 W every 2 minutes. The test was terminated when the subjects reached exhaustion, or if the cadence fell below 65 rpm. Investigators provided verbal encouragement to the sub-

Table I Characteristics of the spinal cord injured road racers

Subject	Gender	Age (yr)	Weight (kg)	Lesion	YSI	10 km time (min:sec)+	Class
1	M	37	69.6	T4	14	27:17	II
2	M	33	58.0	T4	30	25:20	II
3	M	29	60.8	T5i	14	24:17*	II
4	F	33	52.4	T10	13	27:21*	III
5	M	40	61.4	T12	14	28:20	III
6	M	28	61.9	T10	8	29:23	IV
7	M	45	67.2	T12i	14	25:53	IV

YSI = years since injury

i = incomplete spinal cord injury

+ represents best 10 km time for current (1987) Invacare Cup road racing season

*World record 10 km wheelchair racing time (at the time of study)

jects to continue exercising as long as possible. A 10-minute rest period followed the onset of exhaustion, after which a 'supramaximal' protocol was administered to verify the attainment of peak oxygen uptake ($\dot{V}O_2$). During this protocol, the subjects exercised at a moderate PO for 2 minutes followed immediately by 2 minutes of ACE exercise at a PO equal to 17 W plus the PO at exhaustion.

Metabolic and cardiopulmonary data were collected on-line in 30-second segments with a microcomputer using a metabolic measurement program (S & M Instrument Co, Doylestown, PA). Pulmonary ventilation (\dot{V}_E , l/min) was calculated from expired volume with a calibrated pressure-sensitive pneumotach. The subjects breathed through a two-way Daniels valve into a 5-litre mixing chamber, from which a sample of air was continuously drawn. Applied Electrochemistry S-3A and Beckman LB-2 analyzers were used to determine the oxygen and carbon dioxide (CO_2) content of the expired air, respectively. Heart rate (HR, bpm) was continuously monitored with a Hewlett-Packard oscilloscope-cardiotachometer and recorded during the final 15 seconds of each exercise stage. Peak $\dot{V}O_2$ (l/min), \dot{V}_E , and respiratory exchange ratio (RER; $\dot{V}CO_2/\dot{V}O_2$) were determined for each exercise stage by averaging the last 2 30-second values. Peak values for PO and physiological variables were defined as the highest level achieved during either the initial ACE test to exhaustion or the 'supramaximal' protocol.

Only data from the 6 male SCI athletes were included in the statistical tests for comparisons with the able bodied comparison group. Mean values for age, body weight, and peak $\dot{V}O_2$, \dot{V}_E , HR, RER, and PO were compared between groups with separate one-way analyses of variance. Spearman-rho rank order correlations were derived to determine relationships between lesion level and peak $\dot{V}O_2$ and lesion level and 10 km time. A Pearson-Product Moment correlation was calculated to determine the relationship between peak $\dot{V}O_2$ and 10 km time. Since the Phoenix AZ race was cancelled, an up-to-date 10 km time was unavailable. Since not all of the subjects had

competed in a previous race simultaneously, the best 10 km time within the current racing season was obtained from each SCI subject and used in the correlational analyses. The criterion level of significance was pre-established as $p \leq .05$. All data are presented as means \pm standard deviation (SD).

Results

Training regime information and 10 km performance

The mean training duration for this SCI group was 6.7 ± 4.0 years. The mean best 10 km time for current (1987) racing season for the male paraplegic road racers was 26.7 ± 1.9 minutes. The best 10 km time for the female paraplegic road racer was a world record time of 27.3 minutes. Training practice data revealed that these SCI athletes averaged 121.1 ± 20.8 km of wheelchair propulsion training per week. Training included organized sessions of speed, interval, hill, and long slow distance protocols. Three of the SCI road racers also participated in a regular upper body weight training program, and the woman road racer implemented wheelchair roller exercise on a weekly basis. Individual training programs are summarized in Table II.

Comparison of male SCI road racers to untrained able bodied males

The male paraplegic road racers were significantly older than the able bodied male subjects (35.3 ± 6.6 vs 23.0 ± 3.9 yr). As a group, the able bodied male subjects were 10 kg heavier in body weight than the SCI males (63.2 ± 4.3 vs 73.4 ± 10.0 kg). However, there was no significant difference in body weight between these groups due to the larger variability in body weight among the male able bodied subjects.

Table III lists the peak levels of PO and physiological responses attained by the male SCI road racers and able bodied subjects during maximal effort ACE exercise. Table IV gives the peak physiological responses during exhaustive upper extremity exercise in the present SCI subject group and endurance-trained SCI athletes from studies since 1986. Compared to the able bodied

Table II Training practices of the spinal cord injured road racers

Subject	Weekly Training Practices
1	hills 2×/wk; intervals 2×/wk; long slow distance 2×/wk; off 1×/wk; 96–160 km/wk
2	speed work 1×/wk; intervals 2×/wk; long slow distance 2×/wk; off 2×/wk; 64–96 km/wk
3	speed work 4×/wk; intervals 1×/wk; long slow distance 1×/wk; weights 1×/wk
4	hills 1–3×/wk; speed work 1–3×/wk; rollers 2×/wk; long slow distance 3×/wk; weights 2×/wk
5	intervals 1×/wk; speed work 1×/wk; hills 1×/wk; long slow distance 1×/wk; 64–112 km/wk
6	long slow distance 4–5×/wk; 80–112 km/wk
7	intervals 1–2×/wk; hills 1–2×/wk; speed work 1–2×/wk; long slow distance 2–3×/wk; weights 3–4×/wk; 128–176 km/wk

×/wk = times per week
 km/wk = kilometers per week

group, the male paraplegic road racers achieved significantly higher levels of peak PO, absolute $\dot{V}O_2$, and $\dot{V}O_2$ expressed per unit of body weight. Peak HR and \dot{V}_E also tended to be higher for the male SCI athletes, but statistical significance was not obtained. There was no significant difference between groups for peak RER.

Five of the 6 male paraplegics and each able bodied subject had either a minor increase (20 ml/min or less) or a decrease in $\dot{V}O_2$ during the ‘supramaximal’ protocol compared to the $\dot{V}O_2$ elicited at the initial point of exhaustion. The plateau in $\dot{V}O_2$ combined with RER values well above unity (range 1.04–1.30) indicated that these subjects obtained their ‘true’ ACE peak $\dot{V}O_2$. One SCI male exhibited a 230 ml/min increase in $\dot{V}O_2$ during the ‘supramaximal’ protocol combined with a high RER of 1.25.

Peak physiological responses of the woman SCI road racer

The woman paraplegic road racer attained peak PO, absolute $\dot{V}O_2$, relative $\dot{V}O_2$, \dot{V}_E , and HR values of 102 W, 1.99 l/min, 38.0 ml/kg/min, 69.8 l/min, and 167 bpm, respectively. The peak values for physiological responses achieved by this subject during maximal effort ACE exercise are displayed in Table V. The woman SCI athlete exhibited a 20 ml/min decrease in $\dot{V}O_2$ and a RER of 1.12 during the supramaximal protocol indicating valid attainment of ACE peak $\dot{V}O_2$.

Relationships among lesion level, peak $\dot{V}O_2$, and 10 km time

No significant relationships were found between lesion level and peak $\dot{V}O_2$ ($r = 0.00$), lesion level and 10 km time ($r = 0.38$), or peak $\dot{V}O_2$ and 10 km time ($r = -0.06$).

Table III Peak levels of power output and physiological responses attained during maximal effort arm crank ergometer tests

	Male paraplegic road racers (n = 6)	Able bodied subjects (n = 9)
Power output (W)	141.7 ± 8.8	111.4 ± 22.7*
Oxygen uptake (l/min)	2.72 ± 0.52	2.22 ± 0.38*
Oxygen uptake (ml/kg/min)	43.1 ± 7.4	30.3 ± 4.3*
Pulmonary ventilation (l/min)	92.8 ± 17.2	74.6 ± 20.3
Heart rate (bpm)	180.3 ± 9.5	173.2 ± 8.5
Respiratory exchange ratio	1.16 ± 0.09	1.22 ± 0.07

Values are mean ± SD

*significant difference between paraplegic road racers and able-bodied subject ($p \leq .05$).

Table IV Peak physiological responses elicited in endurance-trained male paraplegic athletes in studies since 1986 and the present study

Reference	N	Age (yr)	Lesion level	Test mode	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)	Heart rate (bpm)
Burkett <i>et al</i> ¹⁸	4	32.8 ± 4.5*	T3-L1	WERG	2.12 ± 0.48*	28.1 ± 2.2	163 ± 24*
Coutts and Stogryn ²	2	25.5 ± 4.9	T9-T12	WERG	3.30 ± 0.18	44.0 ± 9.5	182 ± 8
Eriksson <i>et al</i> ³	5	39.0 ± 5.0	T4-T7	ACE	1.20 ± 0.10	17.4 ± 2.2	165 ± 10
Eriksson <i>et al</i> ³	4	37.0 ± 6.0	T12-L2	ACE	2.40 ± 0.10	34.7 ± 1.2	182 ± 8
Flandrois <i>et al</i> ⁴	17	31.0 ± 4.0	T10-T12	WC on rollers	2.16 ± 0.38	33.6 ± 6.7	183 ± 13
Gass and Camp ⁵	6	27.5 ± 2.3	T10-T12	WC on TM	2.86 ± 0.17	47.5 ± 4.4	190 ± 2
Okuma <i>et al</i> ⁶	8	30.8 ± 6.7	T7-L1	WC on TM	2.44 ± 0.34	46.5 ± 6.8	169 ± 20
Present study	6	35.3 ± 6.6	T4-T12	ACE	2.72 ± 0.52	43.1 ± 7.4	180 ± 10

Values are mean ± SD

* value calculated from available data

WERG = wheelchair ergometry

ACE = arm crank ergometry

WC = wheelchair

TM = treadmill

Discussion

As indicated by the best 10 km times (Table I), the SCI group comprised Open Division wheelchair road racers of elite status. The mean best 10 km racing speed for the male paraplegics was 6.25 m/sec. This mean racing speed exceeds and approaches the individual world record 5000 m (5.75 m/sec) and marathon (6.40 m/sec) speeds, respectively, recently reported for male paraplegics.¹⁰ The woman paraplegic road racer's best 10 km speed was 6.08 m/sec which is noticeably faster than the individual world record 5000 m speed (4.67 m/sec) recorded previously by a woman paraplegic.¹⁰ This SCI group's motivation for athletic excellence is reflected in their dedication to rigorous and sophisticated training regimes. Indeed, training practices of the SCI athletes in the present study (Table II) are similar to those previously reported for other elite wheelchair-dependent road racers.¹

The male SCI road racers elicited a significantly higher (by 18%) peak $\dot{V}O_2$ than the male able bodied group during maximal effort ACE exercise. It has been previously demonstrated that arm volume and arm strength contribute to ACE peak

PO achieved by able bodied subjects.¹¹ The difference in peak upper body aerobic power between groups may, therefore, be due to the 27% higher PO achieved by the paraplegic road racers as a result of enhanced upper body muscle strength and muscle endurance via intense wheelchair propulsion training. Unfortunately, measures of arm strength were not obtained in this study. It has also been stated that peripheral (ie muscular), rather than central (ie cardiovascular) training adaptations are more likely to occur during training with small upper body muscle groups.^{4,12-14} However, the capacity for male paraplegic road racers to achieve a higher upper body peak aerobic power than male able bodied subjects via augmented central circulatory function cannot be completely excluded. Davis *et al*¹⁵ observed significant increases in peak left ventricular stroke volume (SV) and cardiac output (Q) in previously untrained paraplegics following 16 weeks of aerobic ACE training. Comparisons of upper body peak SV and Q have not been conducted before and after wheelchair propulsion training nor between SCI athletes and able bodied subjects. These data

Table V Peak physiological responses elicited in able bodied and paraplegic women subjects in previous studies and the present study

Reference	N	Age (yr)	Lesion level	Test mode	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)	Heart rate (bpm)
Fitzgerald <i>et al</i> ²¹	5	24.6 ± 1.2	AB	WERG	1.48 ± 0.48	22.9*	—
Sedlock <i>et al</i> ²⁴	9	24.0 ± 2.3	AB	ACE	1.27 ± 0.36	21.7*	161 ± 18
Vander <i>et al</i> ²³	10	28.8 ± 4.3	AB	ACE	1.60 ± 0.26	27.7 ± 5.3	169 ± 12
Burkett <i>et al</i> ¹⁸	5	29.0 ± 7.3*	T4–T10	WERG	0.87 ± 0.18*	15.9 ± 2.2	166 ± 25*
Coutts and Strogryn ²	1	22	T10/11	WERG	1.42	28.9	192
Fitzgerald <i>et al</i> ²¹	5	27.0 ± 1.7	T9–L4	WERG	1.14 ± 0.10	19.34*	—
Morris ²⁰	1	25	T3/4	ACE	1.32	20.3	161
Tahamont <i>et al</i> ²²	6	27.3 ± 6.4	T10–L4	WERG	0.90 ± 0.11	14.8 ± 2.5	150 ± 27
Vander <i>et al</i> ²³	7	34.0 ± 10.0	T1–T12	ACE	0.77 ± 0.11	14.0 ± 1.4	172 ± 13
Present study	1	33	T10	ACE	1.99	38.0	167

Values are mean ± SD

*value calculated from available data

AB = able-bodied

WERG = wheelchair ergometry

ACE = arm crank ergometry

need to be collected before definitive statements regarding the peripheral muscular and central circulatory contributions to upper body peak aerobic power in SCI paraplegics can be made.

Previous comparisons of peak aerobic power have depicted similar levels of cardiopulmonary fitness in SCI athletes and untrained able bodied subjects.^{3,4} These findings contrast with results of the present study showing markedly higher upper body peak $\dot{V}O_2$ in highly competitive SCI paraplegic road racers than untrained able bodied persons. The reason(s) for discrepancy between studies is known. However, less vigorous aerobic training practices, higher lesion levels, less functional upper body muscle mass, or less subject motivation may have contributed to the lower upper body peak aerobic power in SCI athletes of previous studies. The upper body cardiovascular fitness level of the sedentary able bodied group in the present study is similar to that observed for other sedentary able bodied populations.¹⁶ A lower-than-normal upper body peak $\dot{V}O_2$ in the present able bodied group, therefore, does not account for the differences between studies. In support of the present study, an extensive review of the literature indicated that low

lesion paraplegic endurance athletes generally exhibit higher levels of upper body cardiovascular fitness than age-matched sedentary able bodied subjects.¹⁷

The mean peak $\dot{V}O_2$ for male paraplegic road racers in this study is comparable to those recently reported for Australian,⁵ Canadian² and Japanese⁶ male paraplegic racers (Table IV); higher than those depicted for Swedish³ and French⁴ male paraplegic racers (Table IV); and considerably greater than that determined for aerobically untrained male SCI paraplegics.^{3,4,17–19} The direct comparison in peak aerobic power with the present able bodied group, as well as indirect comparisons with other wheelchair-dependent subjects indicate that upper body exercise training can promote substantial improvements in cardiopulmonary fitness in SCI persons. However, the ACE peak $\dot{V}O_2$ attained in the present group of elite SCI athletes does not approach ACE peak $\dot{V}O_2$ levels achieved by upper body endurance-trained able bodied athletes.¹⁶ There may be a physiological limit to the upper body peak aerobic power attainable by SCI paraplegics due to (1) a large inactive muscle mass due to paralysis below the lesion level (especially in high lesion paraplegics),⁴ and/or (2) the presence of

hypokinetic circulation during upright upper body exercise attributable to sympathetic dysfunction resulting from spinal cord injury.¹³

Interestingly, the woman paraplegic road racer achieved a 27% higher peak aerobic power in ml/kg/min than the able bodied men. Her peak $\dot{V}O_2$ of 38.0 ml/kg/min was higher than the individual peak $\dot{V}O_2$ elicited by 8 of the 9 able bodied male subjects and her absolute peak $\dot{V}O_2$ of 1.99 l/min was only 230 ml/min lower than the mean absolute peak $\dot{V}O_2$ for able bodied men. The extraordinary upper body cardiovascular fitness level of this woman SCI athlete is clearly apparent when comparing her to previously studied wheelchair-dependent and able bodied women (Table V). The peak $\dot{V}O_2$ of the woman paraplegic road racer in the present study is markedly higher than that previously reported for trained SCI women,^{2,20} untrained SCI women,^{18,21-23} and untrained able bodied women.^{23,24} The striking difference in peak aerobic power between this highly competitive woman paraplegic road racer and other SCI and able bodied women further supports the notion that wheelchair exercise training can substantially improve upper body cardiopulmonary fitness in SCI persons. Indeed, the training regime of this SCI athlete (subject 4, Table II) was one of the most rigorous and well balanced programs observed for any of the SCI road racers studied.

Previous studies have noted a significant relationship between lesion level and physical working capacity²⁵ and lesion level and upper body cardiopulmonary fitness^{3,4,8,18,26} in wheelchair-dependent persons. Individuals with lower lesion levels generally have more available functional muscle mass which results in higher peak power output²⁵ and aerobic power²⁶ during exhaustive upper body exercise. The relatively small sample size, heterogeneity in completeness of injury, similarity in training practices among the paraplegic road racers, and exclusion of quadriplegic subjects reduced the probability of obtaining a significant correlation between lesion level and ACE peak $\dot{V}O_2$ in the present study. However, the highest peak $\dot{V}O_2$ (3.65 l/min; 54.8 ml/kg/min) was elicited by a male

paraplegic (subject 7) with the lowest lesion level (T12). To our knowledge, this is the highest individual peak aerobic power reported for a male paraplegic to date. This subject was also, at age 45, one of the older paraplegic athletes tested to date.

Lesion level was also not well correlated with 10 km time. This finding agrees with results documenting that wheelchair racing speed did not become faster as the level of disability became less in paraplegic track athletes.¹⁰ Hedrick *et al*¹ also observed that disability level was not predictive of the SCI athlete's elite status as a wheelchair road racer. It was determined by Hedrick *et al*¹ that the training programs of SCI athletes whose best 10 km times were one standard deviation faster than other Open Division competitors were generally characterized by greater consistency and intensity. The road racers in the present investigation (a self selected subject group) had similar training regimes, as well as similar wheelchair 10 km performances. Together, the present and former findings suggest that, with implementation of the appropriate training practices, SCI paraplegics of varying lesion level can compete equitably in wheelchair road racing events.

The current study also revealed a nonsignificant correlation between ACE peak $\dot{V}O_2$ and 10 km time, both of which exhibited a relatively narrow range of values. It is not known if high ACE cardiopulmonary fitness translates to successful wheelchair exercise performance. However, within the limitations of this study, it appears that upper body peak aerobic power is not the primary factor influencing wheelchair road racing performance in events lasting 24–30 minutes. Similar data have been presented for competitive able bodied 10 km runners who were homogeneous with respect to maximal $\dot{V}O_2$ obtained during treadmill exercise.²⁷ Interestingly, subject 3, the male 10 km world record holder at the time of this study, had a T5 lesion (class II) and the lowest measured peak $\dot{V}O_2$ among the six male SCI road racers. Subject 6 (T10 lesion level/class IV) exhibited the second highest ACE peak $\dot{V}O_2$ among the male paraplegics, yet reported the slowest best 10 km time. For subjects in the present study,

there was a clear dissociation between ACE peak $\dot{V}O_2$ and 10 km wheelchair racing performance. Further investigation of the following variables may yield information as to which factors limit wheelchair road racing performance: genetic endowment, upper body muscle strength, physical fitness/activity level prior to spinal cord injury, training practices employed, upper body anaerobic power, nutritional practices, wheelchair racing experience, wheelchair propulsion economy, wheelchair propulsion biomechanics, wheelchair design (eg pushrim diameter, number of wheels, steering mechanisms), and psychological status.

Conclusion

The data indicate that chronic, intense wheelchair propulsion exercise training can enhance upper body cardiopulmonary fitness to levels higher than demonstrated for healthy, untrained able bodied persons. It also appears that consistent and rigorous

wheelchair propulsion exercise training may offset differences in disability enabling SCI paraplegics of varying lesion level to compete equally in wheelchair road racing. The lack of a significant relationship between ACE peak aerobic power and 10 km time strongly suggests that factors other than upper body cardiopulmonary fitness influence wheelchair road racing performance. However, more extensive research is required to isolate the factors that contribute most to successful wheelchair road racing performance.

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