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The aerobic performance of trained and untrained handcyclists with spinal cord injury.

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ABSTRACT

The purpose of this study was to compare the cardiorespiratory response and mechanical efficiency (ME) of highly trained spinal cord injured (SCI) handcyclists with untrained SCI men. Ten trained handcyclists (≥ 2yr training) and 10 untrained but physically active SCI men completed an incremental exercise test to exhaustion and a sub-maximal test (50 and 80W) on an electro-magnetically braked arm ergometer. The trained participants completed a questionnaire on their training and race performance over the past year including; average training volume (in kilometers), number of training sessions per week and best 20 km time trial.

The trained SCI men had higher $\dot{V}O_2$ peak, peak power ($p \leq 0.001$) and peak heart rate ($p=0.021$) compared to the untrained SCI men. The trained men had higher ($p \leq 0.001$) ME at 50 W (14.1 ± 2.0 %) and 80 W (17.2 ± 2.6) compared to the untrained men (50 W; 12.5 ± 1.8 and 80 W; 15.7 ± 2.1). Peak power ($r=-0.87$, $p=0.001$), $\dot{V}O_2$ peak ($r=-0.67$, $p=0.033$) and ME ($r=-0.58$, $p=0.041$) were negatively correlated with the participants best 20 km time trial. Multiple linear regression indicated peak power ($p<0.001$) and $\dot{V}O_2$ peak ($p=0.021$) were the best predictors (87%) of 20 km time trial performance Highly trained SCI handcyclists have a greater aerobic capacity and ME compared to untrained SCI and are able to reach their maximum age-predicted heart rate during an incremental exercise test. The best predictor of 20 km race performance in highly trained SCI handcyclists is peak power attained during an incremental exercise test.

Key words: Peak oxygen uptake; ventilatory threshold; paraplegia; handcycle

INTRODUCTION

Handcycling is a form of cycling that enables spinal cord injured (SCI) as well as able bodied individuals to ride a bike exclusively using the upper body. For the SCI, handcycling is commonly used in rehabilitation (Valent et al. 2009) sporting programs (Faupin et al. 2008) and as a mode of exercise to improve health and the quality of life (Hettinga et al. 2010).

Compared to conventional hand rim wheelchair propulsion, handcycling is a more mechanically efficient mode of exercise (Dallmeijer et al. 2004; Hintzy et al. 2002) with considerable less physical strain on the upper body (Glaser et al. 1980; Sawka et al. 1980). Furthermore daily wheelchair use has been shown to be of insufficient stimulus to improve physical capacity (Janssen et al. 1994) whereas handcycling is now recommended to improve the level of physical fitness and to prevent cardiovascular disease in SCI (Abel et al. 2006).

The increasing use of the handcycle by SCI as a mode of exercise has led to more handcycles being developed for the purpose of being used in elite sport and competition. As a result handcycling made its first appearance at the Paralympic Games appearance in Athens, Greece in 2004. Marathon events and a European Handcycle Circuit have now also been established with race distances varying from 10km up to 174km (Abel et al. 2006). However despite its increasing popularity as a competitive sport little is presently known about the physiological and performance characteristics of elite SCI handcyclists.

Although some studies (Janssen et al. 2001; Knechtle et al. 2004; Verellen et al. 2004) have examined the aerobic capacity of trained SCI handcyclists, large difference in peak oxygen consumption ($\dot{V}O_2$ peak), peak power and other performance variables such as efficiency have been reported among studies. In particular, mechanical efficiency (ME) which has been identified as an important variable in elite cycling (Leirdal and Ettema 2011) has shown considerable variation (Goosey-Tolfrey and Sindall 2007; Hopman et al. 1995; Verellen et al. 2004). The disparity among reported results may be due to a number of confounding factors such as a lack of studies examining performance indicators of elite SCI handcyclists, training status of participants and the level of lesion or injury. To minimize the differences in injury and physiological function among SCI competitors the Union Cycliste Internationale (UCI) recently established a new classification system (Union 2011). This was implemented to ensure an athlete's success in competition relies on training, physical fitness and talent and not on their level of impairment.

Due to the lack of current studies examining the aerobic performance of elite SCI handcyclists and with the advent of the new level of classification, the establishment of physiological markers and performance indicators of elite SCI handcyclists is warranted. This information will aid in the development of elite SCI handcyclists and identify key components to maximize their performance. Therefore the purpose of this study was to examine the cardioirespiratory responses of trained SCI handcyclists and compare their responses to physically active but untrained SCI during maximal arm cranking. A second aim was to determine the best predictors of 20 km race performance in highly trained SCI handcyclists.

METHODS

Participants

Twenty (10 highly trained handcyclists and 10 untrained SCI men) volunteered to participate in the study. Specific information on level and length of impairment, classification, and anthropometric characteristics are summarized in Table 1. The trained SCI men have participated in handcycle training for over 2yr and regularly participated in national and international road cycling competitions. The untrained but physically active SCI men (less than 2 sessions per week) participated in swimming, basketball, tennis and gym sessions. All participants were classified using the Union Cycliste Internationale classification system under which the sport of handcycling is governed (Union 2011). Each participant identified as potentially suitable for the study attended the laboratory on three separate occasions for screening and familiarisation. On these occasions, each participant (1) was provided with an information sheet setting out details of the experiment, (2) completed a medical history and training and physical activity questionnaire, (3) undertook spirometry and a resting 12 lead electrocardiogram (ECG). The study conformed to the standards set by the Declaration of Helsinki and was approved by the University of the Sunshine Coast Ethics Committee with written informed consent obtained from all participants.

Peak Aerobic ($\dot{V}O_2$ peak) Test

The upper body VO_2 peak test was conducted on a modified electro-magnetically braked cycle ergometer (EE) (Excalibur Sport, Lode B.V., Netherlands). The EE was fixed to a table with the table fixed to the ground to prevent any movement in the EE during the $\dot{V}O_2$ peak test. A modified chair was also fixed to the ground and participants were advised to keep their feet flat on the ground and remain seated throughout the $\dot{V}O_2$ peak test. The seat height and back rest were adjusted so that with the crank position on the opposite side to the body and the hand grasping the handles, the elbow joint was almost in full extension (165-175°) and the shoulders in line with the centre of the ergometers shaft. For the trained SCI men the test began with a 2-min warm-up at a constant power of 45 W. This was followed by a ramp protocol beginning at 60 W with increments of 12 W every minute (1 W every 5 s) (Smith et al. 2004). The untrained SCI men began with a 2-min warm-up at a constant power of 30W and a ramp protocol beginning at 45 W with increments of 6 W every minute (1 W every 10 s) (Lasko-McCarthey and Davis 1991) All participants handcycled at a self selected crank rate (Smith et al. 2007) until volitional exhaustion or until fly wheel revolutions dropped below 60 rpm. A blood sample was taken from the finger tip three minutes after the $\dot{V}O_2$ peak test for the determination of blood lactate concentration $[La^-]$ (Lactate Pro, Arkray, Japan).

Sub-maximal aerobic test

Mechanical efficiency was measured during two 4 min constant load (50 and 80 W) exercise bouts separated by 1-min recovery (Goosey-Tolfrey and Sindall 2007). Cadence was fixed at 70 rev· min^{-1} as changes in cadence during arm cranking have been shown to influence oxygen consumption and efficiency (Smith et al. 2001). Mechanical efficiency was calculated as the ratio of work achieved to the amount of energy expended over the last minute of each 4 min exercise stage. Metabolic energy expenditure was calculated from the $\dot{V}O_2$ and respiratory exchange ratio (Peronnet and Massicotte 1991). Mechanical efficiency was then defined as: ME = (work/energy expenditure) x 100(%).

Cardiorespiratory measurements

Cardiorespiratory-metabolic variables were measured using open circuit spirometry (Parvo-Medics TrueOne® 2400 Metabolic Measurement System, Sandy, UT). Heart rate (HR) was measured via a HR monitor (Polar S610 HR Monitor, Polar Electro Oy, Kempele, Finland) strapped against the participant's chest. During the progressive exercise test, each participant was encouraged to give a maximal effort. Peak values for oxygen consumption were calculated from the average of the last minute of exercise before volitional fatigue. $\dot{V}O_2$ peak was confirmed when three or more of the following criteria (Bernardi et al. 2010) were met: (1) a plateau in $\dot{V}O_2$ despite an increase in ergometer power; (2) a respiratory exchange ratio (RER) higher than 1.15; (3) a heart rate within 10 bpm of its predicted maximum; (4) a lactate concentration higher than 8 mmol l^{-1}.

Determination of Ventilatory threshold (VT)

The VT was identified for each participant from the $\dot{V}O_2$ peak data using the ventilatory equivalent method (Caiozzo et al. 1982): That intensity of activity which causes the first rise in the ventilatory equivalent of oxygen ($\dot{V}E/O_2$) without a concurrent rise in the ventilatory equivalent of carbon dioxide ($\dot{V}E/CO_2$). For each of the individual VT calculations, two trained researchers independently and randomly visually evaluated the graphs of the data to determine VT. If the two values were within 3% (mL·min^{-1}), then those values were averaged and accepted. If the values were more than 3% different, a third trained researcher then independently analyzed the exercise test data to adjudicate the determination of VT. The third VT value was then compared with those of the initial investigators. If the adjudicated VT value was within 3% of either of the initial investigators, then those two VT values were averaged. Once the time of occurrence of the VT was determined power output, $\dot{V}O_2$ and HR at this intensity were recorded and then expressed as a percentage of the peak VO_2 and peak HR during the $\dot{V}O_2$ peak test.

Training and physical activity questionnaire

The trained handcyclists completed a training questionnaire based on their regular training program. Questions included years of handcycle training, average training volume per week (in kilometers), number of training sessions per week and best 20 km time trial completed over the past year. The untrained participants completed a physical activity questionnaire to assess their current level of physical activity. The untrained SCI men participated in recreational gym, tennis and swimming activities but were considered untrained if they participated in less than two regular training sessions per week.

Statistics

Group mean differences for participant anthropometric and cardiorespiratory characteristics were analyzed using independent sample *t*-tests. Associations between $\dot{V}O_2$ peak data, ME and performance characteristics for the trained handcyclists were assessed using Pearson's product-moment correlation. A stepwise multiple linear regression analysis was used to establish the most important determinants of 20 km time trial performance. Statistical significance was set at $p \leq 0.05$. Data are reported as means ± SD. Statistical analyses were performed using SPSS 19.0 for Windows (Chicago, IL).

RESULTS

Individual anthropometric, injury description and classification are shown in Table 1. There was no difference in age, height or body mass between the two groups.

The $\dot{V}O_2$ peak and VT data for the trained and untrained SCI men are summarized in Table 2. All of the trained SCI men achieved at least three of the four $\dot{V}O_2$ peak criteria with six of the ten untrained SCI men achieving the criteria for $\dot{V}O_2$ peak. The trained SCI men had higher $\dot{V}O_2$ peak (absolute and relative), peak power, and peak HR (p=0.021) compared to the untrained SCI men. There was no difference between the two groups in post $\dot{V}O_2$ peak blood lactate concentration. At VT the trained SCI men had greater $\dot{V}O_2$ ($p \leq 0.001$) but there was no difference in HR and $\dot{V}O_2$ or HR when expressed relative to peak HR and $\dot{V}O_2$.

The training and performance data for the trained SCI men are shown in Table 3. The trained men have been training for 6 ± 3.6 yr with 6 ± 1.5 training sessions per week for an average training distance of 222. 5 ± 57.1 km per week. Best time trial performance ranged from 30.04 min to 37.30 min for the 20 km distance. A comparison of ME between trained and untrained SCI men at 50 and 80 W is shown in Figure1. The trained men had significantly higher ME at 50 W (14.1 ± 2.0 %) and 80 W (17.2 ± 2.6) compared to the untrained men (50 W; 12.5 ± 1.8 and 80 W; 15.7 ± 2.1).

Pearson's correlation analysis revealed that peak power (r=-0.87, p=0.001) and $\dot{V}O_2$ peak (r=-0.67, p=0.033) and ME (r=-0.58, p=0.041) were negatively correlated with the participants best 20 km time trial. Multiple linear regression indicated that peak power (p<0.001) and $\dot{V}O_2$ peak (p=0.021) were the best predictors (87%) of 20 km time trial performance (Table 5).

DISCUSSION

Presently little data exists on the physiological and performance profile of long-term trained SCI handcyclists. This study measured the aerobic capacity of trained SCI handcyclists (≥2 yr) and compared their results to untrained but physically active SCI men. The main findings were that a) trained handcyclists had significantly greater aerobic capacity and ME compared to their untrained counterparts b) $\dot{V}O_2$ peak and peak power during the $\dot{V}O_2$ peak test were significantly correlated with the best 20 km time trial of the trained SCI men.

The $\dot{V}O_2$ peak of the trained SCI men of the present study were similar to some (Knechtle et al. 2004) but not all studies (Meyer et al. 2009; Verellen et al. 2004) examining the effect of long term handcycling in SCI. Indeed one of the few studies (Janssen et al. 2001) to compare aerobic capacity and race performance in trained handcyclists reported a mean $\dot{V}O_2$ peak of 2.12 $L \cdot min^{-1}$which was well below the values found in the present study (3.17 $L \cdot min^{-1}$). However the men of the present study have been competitively handcycling for over 6 yr and have a considerably greater training volume (Table 3) than those reported by Janssen et al. (2001). Furthermore advances in handcycle technology and design over the past 10 yr may have also improved training and performance measures (Hettinga et al. 2010). The greater $\dot{V}O_2$ peak of the trained SCI men (~ 40%) in the present study compared to their age-matched counterparts indicates that that long-term regular aerobic training in SCI leads to similar improvements in aerobic capacity seen in able body individuals (Wray et al. 2007). This has important consequences not only for improving the aerobic capacity of SCI men involved in elite competition but also in the prevention of cardiovascular disease due to inactivity and sedentariness for those with SCI (Fernhall et al. 2008).

The ME of the trained SCI men was similar to other studies (Goosey-Tolfrey and Sindall 2007) of long-term trained handcyclists but higher than moderately trained or untrained SCI men (Hopman et al. 1995; Verellen et al. 2004). Higher ME values have been reported elsewhere (Groen et al. 2010; Verellen et al. 2011) however participants were able bodied and handcycled at higher workloads. When exercise intensity is high with RER values above 0.9 it has been suggested that part of the energy contribution may be from anaerobic pathways with ME values subsequently being over estimated. The present study used 50 and 80 W to ensure minimal anaerobic energy contribution to ME estimations. Further confounding influences on ME is the position of the rider (kneeling vs. seated) and whether cranking is synchronous or asynchronous (Goosey-Tolfrey and Sindall 2007; Verellen et al. 2011). All participants in the current study were in the seated position and used synchronous arm cranking.

Peak power achieved during the $\dot{V}O_2$ peak test was considerably higher for the trained SCI men compared to the untrained SCI men. The greater peak power for the trained group is most likely due to improved central and peripheral aerobic factors rather than improved muscular size and strength as endurance training does not appear to improve muscular strength in SCI (Jacobs 2009). Furthermore studies have reported a lack of a significant correlation between $\dot{V}O_2$ peak and muscle mass and strength in SCI (Faria et al. 2005) Peak HR achieved during the $\dot{V}O_2$ peak test was higher for the trained SCI men compared to the untrained SPI men. The peak HR of the trained SCI men (184 bpm) was also above the predicted (220-age) value (180 bpm) with the untrained SCI men peak HR (168 bpm) below the predicted value (183 bpm) for their group. The failure of the untrained SCI men to reach their predicted peak HR is commonplace in untrained SCI (Arabi et al. 1997) and able bodied (Al-Rahamneh and Eston 2011) participants during upper body $\dot{V}O_2$ peak tests and is most likely due to a lack of peripheral adaptations in the upper body (Calbet et al. 2005) preventing a maximal response of the cardiovascular system. The lack of upper body adaptations may also explain why only six of the ten untrained men achieved three of the four $\dot{V}O_2$ peak criteria. In contrast adaptations in the upper body due to long-term aerobic training may have reduced the effect of peripheral limitations in the trained SCI men with central factors contributing more to the limitation in $\dot{V}O_2$ peak (Bhambhani 2002; Saltin and Calbet 2006) and as a result all trained SCI men achieved the criteria for $\dot{V}O_2$ peak.

For the trained SCI men of the present study $\dot{V}O_2$ peak and peak power and ME were significantly correlated to the participants best 20 km time (Table 4). Similar findings have been reported elsewhere with VO_2 peak and peak power correlated with wheelchair athletes with paraplegia and quadriplegia (Bhambhani et al. 1995; Lakomy et al. 1987) and trained handcyclists (Janssen et al. 1994). However unlike the present study Janssen at al, (2001) found that ME was not correlated to race performance. This may be due to the participant's lower aerobic capacity (2.12 $L{\cdot}min^{-1}$) and training status compared to the present study (3.17 $L{\cdot}min^{-1}$). Furthermore ME was measured at lower workloads (28 and 38 W) compared to the present study (50 and 80 W) with higher workloads similar to racing demands demonstrating higher efficiencies and therefore more closely correlated to race performance (Verellen et al. 2004). Peak power and to a lesser extent $\dot{V}O_2$ peak were found to be the best predictors of 20 km cycle time of the trained SCI handcyclists, explaining 87 percent of the variance. Similar results have been reported elsewhere by trained SCI handcyclists (Janssen et al. 1994) and in cross country ski performance in able bodied athletes (Fabre et al. 2010).

The comparison of SCI data from the present study with other studies must be treated with caution. There are a number of confounding factors that may influence the aerobic and race performance indicators. Many studies include not only paraplegic athletes but a number of other athletes with varying degrees of disabilities in their results (Bernardi et al. 2010; Bhambhani 2002). Furthermore the level of lesion in SCI can also influence athlete's performance (Lassau-Wray and Ward 2000). In addition most studies only involve wheelchair athletes and consequently only conduct maximal testing on a wheelchair. The different movement patterns between handcycle and wheelchair athletes may limit any direct comparison between the two modes of exercise (Hettinga et al. 2010).

CONCLUSIONS

The trained SCI handcyclists attained higher $\dot{V}O_2$ peak and peak power during an incremental exercise test on an arm ergometer compared to untrained SCI men. Furthermore the training SCI men displayed greater cycling efficiency at sub-maximal workloads compared to the untrained SCI men. The untrained group also appears to be unable to reach a true $\dot{V}O_2$ peak as evidence by not reaching their age-predicted maximum HR whereas the trained group surpassed their age-predicted maximum HR. It would therefore appear that long-term handcycling enables SCI men to overcome peripheral limitations and maximize their cardiovascular system during incremental exercise testing. For elite handcyclists $\dot{V}O_2$ peak and peak power attained during an incremental exercise test would appear to be the best predictors of 20 km time trial performance.

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Table 1. Anthropometric, injury description and classification data.

	Age (yr)	Body Mass (kg)	Height (cm)	Injury Description	Duration of injury	UCI classification
Trained						
T1	48	92.1	182.3	T6/7 (complete)	27	H2
T2	27	90.6	178.2	T9/10 (complete)	8	H2
T3	41	85.8	178.3	T5(complete)	14	H2
T4	49	76.4	170.8	T10/11 (complete)	17	H2
T5	42	73.2	178.2	T7 (complete)	4	H2
T6	32	75.2	178.2	L1 (incomplete)	6	H3
T7	49	80.5	168.1	T12/L1 (incomplete)	30	H3
T8	46	80.1	146.5	L3,4,5 Spina Bifida	Birth	H3
T9	36	70.6	159.5	T12 (complete)	15	H3
T10	38	90.4	178.7	T12/L1 (incomplete)	8	H3
Mean	41	81.5	171.9			
SD	8	7.8	11.3			
Untrained						
UT1	37	107.4	183.3	T10 (incomplete)	8	H2
UT2	38	66.2	170.7	T11/12 (complete)	2	H2
UT3	42	83.3	193.2	T6 (complete)	15	H2
UT4	27	80.5	176.8	T5/6 (complete)	9	H2
UT5	30	95.1	176.1	T7 (complete)	16	H2
UT6	41	82.2	177.1	L2/L3 (complete)	10	H3
UT7	32	77.2	169.4	L1 (complete)	6	H3
UT8	38	74.4	161.6	T12/L1 (complete)	9	H3
UT9	42	86.6	180.6	T10 (incomplete)	12	H3
UT10	45	95.2	176.2	T4/5 (complete)	3	H4
Mean	37	84.8	176.5			
SD	6	11.9	8.60			

UCI = Union Cycliste Internationale;

Table 2. Incremental exercise test data

Variable	Trained (n=10)	Untrained (n=10)	*p*
VO_2peak (L·min^{-1})	3.17 ± 0.43	1.70 ± 0.41	0.00
(mL·kg^{-1}·min^{-1})	40.4 ± 5.5	21.23 ± 4.7	0.00
Peak Power (W)	210 ± 22	121 ± 30	0.00
Peak HR (bpm)	184 ± 11	172 ± 12	0.02
RER	1.19 ± 0.06	1.16 ± 0.07	0.23
Blood Lactate (mmol·L^{-1})	11.74 ± 2.31	10.53 ± 4.02	0.35
VT VO_2 (L·min^{-1})	2.26 ± 0.32	1.40 ± 0.30	0.00
VO_2 (% peak)	74.09 ± 6.37	76.25 ± 6.40	0.48
HR (bpm)	160 ± 14	144 ± 20	0.03
HR (% peak)	86.69 ± 3.69	82.44 ± 9.00	0.18

Values are means ± SD. VO_2 peak = peak oxygen consumption; HR = heart rate; VT = ventilatory threshold;

Table 3. Performance and training data of trained handcyclists

	Years of handcycling	Sessions per week	Training km/wk	Best 20 km TT (min:sec)
T1	3	6	150	34.41
T2	3	4	150	34.34
T3	5	6	275	35.00
T4	6	4	200	36.12
T5	3	9	275	35.17
T6	7	8	250	35.17
T7	12	6	300	30.04
T8	12	6	250	37.30
T9	2	5	150	35.02
T10	5	6	225	35.17
Mean	6	6	222.5	34.77
SD	3.6	1.5	57.1	1.87

Values are means ± SD. TT = time trial; km = kilometers; wk = week.

Table 4. Correlation coefficients between best 20 km time trial and performance variables

	VO_2 peak	Peak power	ME
20 Km TT	-0.67	-0.87	-0.58
	(p=0.033)	(p=0.001)	(p=0.041)

ME= mechanical efficiency at 80 W

Table 5. Predictors of best 20 km time trial

	Adjusted R^2	F value	Predictors	Standardized β coefficient	P
20 Km TT	0.87	$F_{1,8}$ = 25.1, p <0.001	Peak power	0.64	<0.001
			VO_2 peak	0.33	=0.021