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Journal of Sports Sciences

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

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First published on: 03 February 2010

To cite this Article Barfield, J. P. , Malone, Laurie A. , Arbo, Crystal andJung, Alan P.(2010) 'Exercise intensity during wheelchair rugby training', Journal of Sports Sciences,, First published on: 03 February 2010 (iFirst)

To link to this Article: DOI: 10.1080/02640410903508839

URL: http://dx.doi.org/10.1080/02640410903508839

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Journal of Sports Sciences, 2010; 1–10, i*First* article

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Exercise intensity during wheelchair rugby training

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(Accepted 24 November 2009)

Abstract

The purpose of this study was to determine the ability of individuals with a cervical spinal cord injury to achieve and sustain a cardiorespiratory training intensity during wheelchair rugby. Nine wheelchair rugby players completed a continuous peak exercise test on a SciFit Pro I arm ergometer with stage increases each minute to determine peak heart rate and power output. Approximately one week after peak exercise testing, heart rate was recorded (every 5 s) during three regularly scheduled rugby training sessions. Data were analysed to determine the number of continuous minutes that participants spent above 70% of heart rate reserve under various rugby training activities. The percent of time spent at or above 70% heart rate reserve varied across participants and conditions. Continuous pushing was the least variable training condition among participants with the sample averaging greater than 73% of time above the target heart rate. Scrimmage training was highly variable across participants with a range of 0% to 98% of time above the criterion. Results of this study indicate that wheelchair rugby training enables some participants to reach a training intensity associated with improved cardiorespiratory fitness, and that the type (or kind) of training activity dictates the extent to which individuals sustain such a threshold.

Keywords: *Spinal cord injury, exercise, prescription, tetraplegia, cardiorespiratory fitness*

Introduction

Regular exercise is associated with multiple positive outcomes among individuals with spinal cord injury, including improved cardiorespiratory fitness (Jacobs & Nash, 2004; Jacobs, Nash, & Rusinowski, 2000), improved muscular fitness (Janssen, Dallmeijer, Veeger, & van der Woude, 2002), improved function (Steadward, 1998), reduced strain during activities of daily living (Janssen et al., 1996), and a reduced risk of secondary disease (Kosma, Cardinal, & Rintala, 2002). The level and severity of injury dictate the chronic adaptations that result from regular exercise and activity outcomes are therefore distinct between individuals with a cervical lesion (i.e. injury sustained at or above the first thoracic spinal cord level) and those with a thoracic-level injury (Figoni, 2003; Haisma et al., 2006). Specific to individuals with cervical spinal cord injury, regular aerobic exercise has been shown to improve peak aerobic capacity, peak power output, muscular strength, and cardiorespiratory response to submaximal exercise (Bizzarini et al., 2005; De Groot, Hjeltnes, Heijboer, Stal, & Birkeland, 2003; Figoni, 2003; Hooker & Wells, 1989; Whiting, Dreisinger, Dalton, & Londeree, 1983). Despite the evidence that regular physical activity benefits individuals with cervical spinal cord injury, a consistent exercise prescription for this population has not been established (Bizzarini et al., 2005; Bougenot et al., 2003; Myslinski, 2005).

Exercise prescription variables include training frequency, intensity, duration, and type. Despite the atypical cardiorespiratory responses to exercise among persons with cervical spinal cord injury, researchers have continued to use heart rate to prescribe exercise intensity. The American College of Sports Medicine (1998) recommends a training intensity of 50% $\dot{V}O_2$ reserve for improving cardiorespiratory fitness, but caution is warranted for this recommendation because of the impaired cardiac drive inherent in cervical spinal cord injury. Specifically, sympathetic innervation of the heart is limited for persons with a cervical spinal cord lesion and the

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ISSN 0264-0414 print/ISSN 1466-447X online © 2010 Taylor & Francis
DOI: 10.1080/02640410903508839

heart rate–oxygen consumption ($\dot{V}O_2$) relationship is not necessarily linear in this population (Valent et al., 2007). However, heart rate reserve has been used with success and a training intensity of 70–80% heart rate reserve has been effective for improving cardiorespiratory fitness among persons in this population (Bizzarini et al., 2005). Hooker and Wells (1989) reported a 24% improvement in $\dot{V}O_{2max}$ following 8 weeks of wheelchair ergometry training at 70% heart rate reserve (20 min, 3 days a week) compared with a 10% improvement at 50% heart rate reserve (20 min, 3 days a week). De Groot and colleagues (2003) also reported significantly better improvement in $\dot{V}O_{2peak}$, the total cholesterol-to-high-density lipoprotein ratio, and insulin sensitivity following 8 weeks of interval training at 70% heart rate reserve (1 h, 3 days a week) compared with 40–50% heart rate reserve. These studies demonstrate that individuals with cervical spinal cord injury can improve peak aerobic capacity, peak power output, and lipid profiles given a sufficient stimulus. Figoni (2003) cautioned, however, that peripheral factors (e.g. improved muscle strength, improved muscle mass) rather than central factors (e.g. improved stroke volume) might explain the majority of improvement in this population. Nevertheless, evidence is emerging regarding proper training intensity, duration, and frequency recommendations; however, training mode is an area in need of further study.

The concerns with prescribing a training mode for persons with cervical spinal cord injury are twofold. First, overuse injuries and muscle pain can result from continuous arm and wheelchair ergometry, causing shoulder pain and loss of activity opportunities (Bernardi et al., 2003; Dyson-Hudson, Sisto, Bond, Emmons, & Kirshblum, 2007; Steadward, 1998). Bernardi et al. (2003) suggest that the risk for sport-related muscle pain increases substantially when wheelchair training volume is greater than 7 h per week. In an effort to reduce overuse injuries in this population, researchers now recommend varying exercise modes for individuals with spinal cord injury, and wheelchair sport is emerging as a viable mode of exercise (Abel, Platen, Rojas Vega, Schneider, & Strüder, 2008; Bizzarini et al., 2005; Figoni, 2003; Nash, van den Ven, van Elk, & Johnson, 2007). Additionally, activity barriers prevent many individuals with disabilities from engaging in regular training and barriers are most restrictive to those with the least function (Jacobs & Nash, 2004; Rimmer, Riley, Wang, Rauwort, & Jurkowski, 2004; Wu & Williams, 2001). Wheelchair sport is a potential remedy to activity barriers and shows promise as a training mode for physical activity-related benefits (Steadward, 1998). To establish wheelchair sport as a suitable training mode, it is imperative to determine if wheelchair sport participants can reach a training intensity (70% heart rate reserve) associated with improvement in cardiorespiratory fitness.

The ability to reach a cardiorespiratory training intensity has been demonstrated for individuals with paraplegia (i.e. two-limb paralysis resulting from injuries below the cervical spinal cord level) during both wheelchair tennis and wheelchair basketball (Coutts, 1988; Perez, Rabadan, Pacheco, & Sampedro, 2007; Roy, Menear, Schmid, Hunter, & Malone, 2006). Unfortunately, much less evidence is available on sports for persons with cervical spinal cord injury (Barfield, Malone, Collins, & Ruble, 2005). Abel and colleagues (2008) reported an energy expenditure of 248.5 ± 69.4 kcal $\cdot$ h^{-1} during wheelchair rugby. This sport is becoming increasingly popular for individuals with physical disabilities and, specific to spinal cord injury, is delimited to individuals with cervical spinal cord injury. Although Abel and colleagues did not specifically examine training intensity, it is plausible that players may achieve moderate to vigorous training intensities based on the reported energy expenditure. If wheelchair rugby players can achieve and sustain a cardiorespiratory training intensity (70% heart rate reserve) during training, then this sport can be recommended as a viable mode for improving cardiorespiratory fitness for persons with cervical spinal cord injury. Therefore, the purpose of this study was to determine the ability of individuals with cervical spinal cord injury to achieve and sustain 70% heart rate reserve during wheelchair rugby.

Methods

Participants

Nine competitive male wheelchair rugby players with cervical spinal cord injury were recruited to the study (Table I). All had previously been classified by the International Wheelchair Rugby Federation (http://www.iwrf.com/classification.htm) based on level of functional ability, with scores ranging from 0.5 points to 3.0. In class 0.5, a head bob is present when pushing. Given limited muscle function, these athletes will pull on the back part of the wheel for push stroke, will use their forearm on the wheel for starts, turns and stops, and will trap direct passes on the lap. This class of athlete uses a two-hand toss for shorter range passes and bats the ball using an underhand volleyball stroke for longer passes. Because of good finger function, 3.0 athletes can grip the wheelchair to increase pushing speed, can control the ball in varying planes of movement for passing, dribbling, catching and protecting, can dribble and pass the ball well with one hand, and multiple dribble one-handed with control (www.iwrf.com). The research was approved by the university's institutional review board and all participants provided written informed consent.

Design

A one-group time series design was used to assess heart rate intensity across multiple wheelchair rugby training days (Figure 1). Peak heart rate was collected one week prior to rugby activity, enabling determination of intensity for each minute of activity during each training session. The same researcher observed each training session to code heart rate responses. Heart rate scores were downloaded following each training session and minutes above 70% heart rate reserve for each activity were determined.

Instrumentation

Peak oxygen uptake ($\dot{V}O_{2peak}$) was measured by a CardioCoach (Korr Technologies, Salt Lake City, UT) metabolic measurement system during exhaustive exercise on a Pro I arm ergometer (SciFit Systems, Inc., Tulsa, OK). The Pro I maintains a constant workload through an electromagnetic braking system, thereby allowing participants to cycle at their preferred speed during each stage. A disposable face mask with a one-way breathing valve was used to collect expired gases, with volumes of gases estimated from partial pressures measured in the mixing

Table I. Descriptive statistics for the participants.

Participant	Age (years)	Height (m)	Weight (kg)	Rugby experience (years)	Rugby class	Injury level	Time since injury (years)
1	42	1.73	53.52	10	0.5	C5/6	19.0
2	37	1.78	67.72	14	1.0	C5/6*	19.0
3	35	1.96	83.01	14	2.0	C6/7	14.0
4	42	1.68	64.05	15	0.5	C5/6	17.0
5	38	2.01	99.93	14	2.5	C6/7	20.0
6	29	1.87	64.41	4	2.0	C6	7.5
7	23	1.78	53.62	2	2.0	C6/7	2.5
8	22	1.85	55.84	1	2.0	C6/7	3.5
9	26	1.88	72.00	6	3.0	C6/7	7.0
Mean	33	1.73	72.28	9			12.0
s	8	0.04	4.19	6			7.1

Note: All injury levels are complete with the exception of Participant 2.

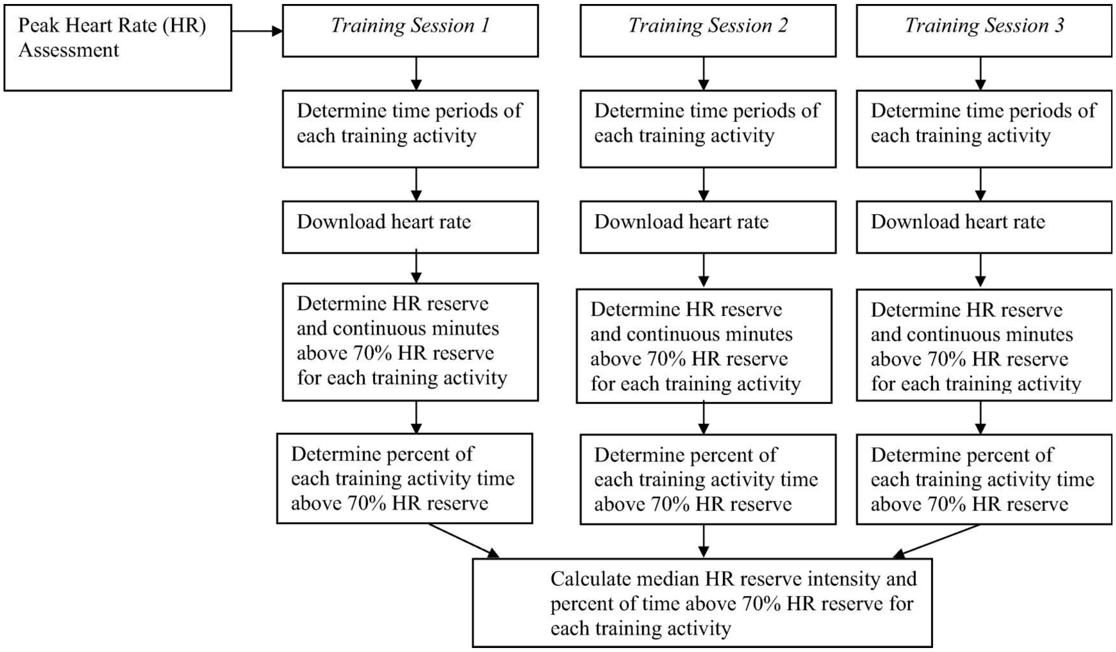

Figure 1. Time-series design used for data collection.

chamber every 15 s. All heart rate measurements obtained during the peak exercise test and wheelchair rugby training were collected by a Polar 610i heart rate monitor at 5-s intervals (Polar, Lake Success, NY). Once collected, heart rate data from the receiver were downloaded and screened to ensure outliers (e.g. zero scores) were excluded from the analyses.

Procedures

Peak testing. The participants entered the laboratory at 30-min intervals. Participants were asked to void their bladder before testing and data collectors measured blood pressure to ensure the participants did not exhibit autonomic dysreflexia. The researchers then collected demographic information, including age, height, weight, sport classification, and time spent in moderate- and vigorous-intensity activity (Behavioral Risk Factor Surveillance System, Centers for Disease Control and Prevention, 2005). A heart rate belt with embedded electrodes and transmitter was positioned around each participant's chest while the receiver was strapped to the athlete's chair. Electrodes on the heart rate monitor were moistened for each participant to ensure the heart rate signal was transmitted appropriately despite the absence of sweating. Participants, seated in their preferred wheelchair, were positioned on the Pro I wheelchair platform and the ergometer axle was adjusted to be parallel to the participant's shoulder and at a distance to allow slight elbow flexion during the shoulder extension phase of rotation (i.e. $\sim$5–10%). Masks were positioned securely on the face, ensuring that no expired air could escape. The researchers then collected resting heart rate after 5 min of no activity.

The peak exercise protocol was based on asynchronous arm ergometry models previously reported in the literature (Claydon, Hol, Eng, & Krassioukov, 2006; Raymond, Davis, Climstein, & Sutton, 1999). Each participant completed a 1-min warm-up at a workload of 10 W. Two participants chose to perform an additional 5-min warm-up because both felt prone to spasms and cramping. After the warm-up, increases in workload were made each minute. Workload was increased by 5 W each minute for participants with a classification below 2.0 and by 10 W for athletes with a classification of 2.0 or above. Oxygen consumption and heart rate were recorded in the final 5 s of each stage. The test was terminated when no further increase in heart rate or $\dot{V}O_2$ was detected after an increase in workload, or the participant reported volitional fatigue. Upon completion of the $\dot{V}O_{2peak}$ test (mean relative humidity = 30.0 ± 0.0%; mean temperature = 25.5 ± 0.8°C; mean presure = 762.5 ± 0.6 mmHg), all participants were immediately encouraged to cool down on the Pro I for a self-determined amount of time at 10 W, followed by a post-test blood pressure check. This second blood pressure measurement, taken approximately 3–5 after cool down, was evaluated to ensure participants were not exhibiting hypotension following exercise (Claydon et al., 2006; Dela et al., 2003). Results of the peak testing are reported in Table II.

Training heart rate assessment. On-court heart rate measurements were collected every 5 s across three regularly scheduled rugby team training sessions. Participants self-inspected their sport chairs and then participated in 90 min of training structured into 10-min activity bouts separated by 3-min breaks. Training activities consisted of the following: warm-up, continuous pushing, pushing/agility drills, passing drills, and scrimmage (see Table III). A spray bottle was used to periodically moisten the heart rate monitor electrodes of players who indicated little or no ability to sweat. This assessment enabled

Table II. Descriptive statistics of participants' activity and peak exercise response scores.

Participant	Moderate intensity (min · week^{-1})	Vigorous intensity (min · week^{-1})	Peak heart rate (beats · min^{-1})	$\dot{V}O_{2peak}$ (ml · kg^{-1} · min^{1})	Heart rate–$\dot{V}O_2$ (*r*)	SEE/ $\dot{V}O_{2R}$ (%)	$\dot{V}O_{2peak}$ (litres · min^{-1})	Peak power output (W)
1	120	240	92	13.00	0.99	0.00	0.70	30
2	120	240	154	20.60	0.97	0.06	1.40	45
3	120	480	120	21.30	0.96	0.08	1.80	90
4	375	310	102	16.20	0.95	0.09	1.00	45
5	120	240	115	13.50	0.93	0.13	1.30	80
6	180	360	118	22.40	0.84	0.20	1.40	75
7	90	270	115	8.20	0.99	0.03	0.40	45
8	360	240	122	13.50	0.82	0.16	0.80	30
9	1050	1260	123	15.40	0.92	0.15	1.10	80
Mean	282	404	118	16.01	0.94	0.10	1.10	58
s	308	331	17	4.65	0.05	0.06	0.43	23

Note: SEE is the standard error of estimate for the individual heart rate–$\dot{V}O_2$ relationship.

determination of minutes above 70% heart rate reserve for each activity on each training day. Post-training examination of data revealed transmitter problems with three data sets, limiting one participant to 2 days of data collection and one participant to 1 day.

Statistical analysis

Heart rate reserve intensities determined across three training days were collapsed into one median score for participants across each training activity. Minutes above 70% heart rate reserve across 3 days were also collapsed into one median score for each participant under each training activity (Figure 1). To determine the ability of individuals with cervical spinal cord injury to achieve 70% heart rate reserve during wheelchair rugby, we calculated the percent of participants who demonstrated at least one continuous minute above the stated intensity for each rugby activity. Since heart rate was collected at 5-s intervals, 12 continuous scores above threshold was the criterion for a continuous minute. To determine the ability of individuals with cervical injuries to sustain 70% heart rate reserve during wheelchair rugby, continuous minutes above 70% heart rate reserve were determined for each activity. Since rugby activity time periods were unequal, percent of time above each threshold was used.

The suitability of reporting one median score for each activity, rather than three separate scores, was examined by two-way intraclass correlation coefficients (ICC). Since the scores were found to be reliable (see Results), we felt separate analyses and discussion for each training session would confound rather than clarify the results.

Results

Wheelchair rugby players averaged training intensities from 51% heart rate reserve during passing drills to 75% heart rate reserve during continuous pushing (Table IV). Although it is important to document average intensity during training, it is equally essential to document the duration players sustained a training intensity across conditions, namely 70% heart rate reserve. All nine participants surpassed this training intensity for continuous pushing and pushing/agility drills (i.e. each participant was able to maintain heart rate above threshold for one continuous minute during specific training activity). During passing drills, 6 of 9 participants (66%) surpassed this threshold and, during scrimmage activity, 7 of 9 participants (77%) surpassed this threshold. Percent

Table III. Description of training activities.

Activity	Description
Warm-up	Self-selected activities for individual warm-up (e.g. wheeling around track, stretching)
Continuous pushing	Continuous wheeling in a figure-of-8 pattern on a hardwood court
Pushing/agility drills	A variety of drills involving wheelchair manoeuvring by the athletes, with combined sequences of pushing and quick changes in direction or location on the court
Passing drills	A variety of drills to work on both short and long passing skill
Scrimmage activity	Practice game play between two units of the team

Table IV. Descriptive statistics for training intensity.

	Continuous pushing	Pushing/agility drills	Passing drills	Scrimmage activity	Total
Activity time (min)					
mean	9.9	18.8	18.9	18.6	64.4
s	.32	2.6	2.7	3.9	11.0
Heart rate (beats · min^{-1})					
mean	114.3	109.4	101.2	104.1	105.7
median	117.5	112.2	100.3	104.4	104.0
s	13.2	11.4	13.7	17.76	13.4
% Heart rate reserve					
mean	75.0	66.7	51.1	54.3	58.5
median	77.1	66.9	43.2	53.9	57.2
s	11.4	14.1	22.9	25.8	16.62
% Time above 70% heart rate reserve					
mean	73.8	49.8	26.0	41.7	40.2
median	84.1	43.3	1.5	39.7	34.2
s	30.1	30.0	38.0	33.5	29.1

of time above 70% heart rate reserve varied across individuals and training activities. Participants spent, on average, more than 40% of continuous pushing, pushing/agility, and scrimmage time at or above 70% heart rate reserve but the variability of these scores across participants was high (Table IV). Based on visual inspection of data, time above intensity did not appear to be influenced by classification level (Figure 2). That is, function did not distinguish between those who exceeded 70% heart rate reserve during training conditions and those who did not. For example, 0.5-point players (lowest function) and 2.0-point players both surpassed the criterion greater than 70% of total training time. Although sample size prevented quantitative analysis of the relationship between rugby classification score and time above threshold, removal of potential outliers (e.g. Participant 2) in a re-analysis of the data did not change mean, median or variance statistics for time above threshold.

It is clear that individuals with cervical spinal cord injury can and do surpass a training intensity associated with important fitness outcomes during wheelchair rugby training. Mean heart rate reliability across training days was strong for continuous pushing (ICC = 0.95), pushing/agility drills (ICC = 0.95), passing drills (ICC = 0.94), and total activity time (ICC = 0.94), supporting the use of one median score for each training activity. Scrimmage scores were not as stable (ICC = 0.41), which is unsurprising because the activity itself is typically less structured. Caution may be warranted for scrimmage but reliability coefficients for rugby training were sufficiently stable to use median scores for data analysis rather than separate daily scores.

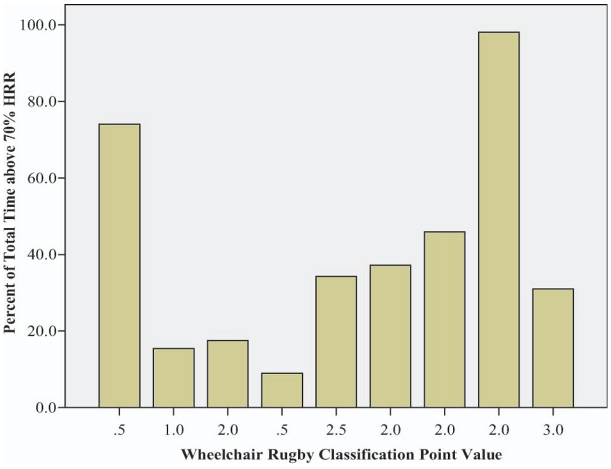

Figure 2. Percentage of total training time above 70% heart rate reserve (HRR) by functional ability (Wheelchair Rugby Classification Point Value).

Discussion

The purpose of this study was to determine the extent to which individuals with cervical spinal cord injury can achieve and sustain a cardiorespiratory training intensity during wheelchair rugby. Our results revealed that wheelchair rugby participants were able to reach and maintain 70% heart rate reserve during training, an intensity associated with improved cardiorespiratory fitness in this population. Furthermore, some participants were able to demonstrate sufficient time above threshold necessary for meaningful exercise prescription. Based on the literature, intensity may be the most important prescription variable for training adaptations among individuals with spinal cord injury. Findings from multiple studies support the benefits of 70% heart rate reserve for improvement in cardiorespiratory fitness within this population (Bizzarini et al., 2005; Whiting et al., 1983). Specifically, De Groot and colleagues (2003) reported significantly better improvements in $\dot{V}O_{2\text{peak}}$, lipid profiles, and triglyceride concentration following 8 weeks of arm cranking at 70–80% heart rate reserve compared with 40–50% heart rate reserve. Hooker and Wells (1989) also reported greater improvement in $\dot{V}O_{2\text{peak}}$, better lipid profiles, and better submaximal responses following 8 weeks of exercise for individuals with spinal cord injury who trained at 70–80% compared with 50–60% heart rate reserve. Based on the current findings, it would appear that wheelchair rugby participants can achieve and maintain high training intensities for sufficient duration to have a beneficial training effect within a sport setting. Therefore, wheelchair rugby appears to be a suitable cardiorespiratory training mode for individuals with cervical spinal cord injury.

Functional ability did not distinguish responders from non-responders, at least among structured activity conditions (e.g. continuous pushing, pushing/agility drills). Athletes with the lowest functionality were able to reach and sustain training intensities to the same extent as individuals with greater function. This finding is important, indicating the ability to achieve a training threshold and resulting benefits may not be limited by injury level or functional ability. It is worth mentioning, however, that functional ability did appear to affect time above threshold for less structured activity (i.e. scrimmage). This finding is likely explained by coaching strategy for low-point players rather than an ability to sustain training thresholds during match-play. Specifically, low-point players are not put in positions to be offensively aggressive during game play (Molik et al., 2008); therefore, movement demands required for the position are limited, ultimately reducing the exercise intensity exhibited.

Duration above training threshold, or percent of time above 70% heart rate reserve, is difficult to compare with other studies in the literature. Perez et al. (2007) examined intensity during wheelchair basketball among individuals with lesions below the cervical level (e.g. paraplegia). These authors reported an average game play intensity of 73% heart rate reserve and a significant, but very weak, relationship between function and training intensity. We reported an average training intensity of 75% heart rate reserve for the current sample during continuous pushing but lower intensities during other training conditions (i.e. 51–67% heart rate reserve). Despite the higher functioning participants in the study of Perez and colleagues, it is important to note the consistent training intensity between the two studies and the lack of relationship between function and intensity achieved. Abel and colleagues (2008) examined a similar sample but reported caloric expenditure during wheelchair rugby training rather than time above a specific intensity. Although caloric expenditure can be converted to heart rate intensity in the able-bodied population, the atypical heart rate–$\dot{V}O_2$ relationship among individuals with cervical spinal cord injury makes this conversion inappropriate (Valent et al., 2007). Lastly, Barfield and colleagues (2005) reported that only 10% of participants with spinal cord injury (C4 to T7) sustained an intensity of at least 55% peak heart rate for 30 min during national-level power soccer competition. Power soccer does not require manual propulsion of the wheelchair and therefore a direct comparison between the two sports is difficult. Nonetheless, disability sport is now being used as a mode to prevent disease, especially cardiovascular disease, and findings from the current study indicate that wheelchair rugby is a viable exercise mode that can be manipulated to enhance cardiorespiratory fitness among persons with cervical spinal cord injury (Abel et al., 2008).

Atypical cardiorespiratory responses to acute exercise and reduced exercise capacity among individuals with cervical spinal cord injury contribute to the difficulty associated with exercise prescription. In response to an exercise stress, acute cardiorespiratory responses are inhibited by several central factors, including reduced lung capacity (McKinley, Jackson, Cardenas, & DeVivo, 1999), decreased sympathetic innervation of the heart (Glaser, 1985), and cardiac muscle atrophy (Van Loan, McCluer, Loftin, & Bioleau, 1987). Sympathetic innervation of the heart is initiated through preganglionic fibres located between the first and fourth thoracic spinal cord levels; hence, cardiac drive is limited in individuals with a cervical lesion. The withdrawal of vagal tone, regulated through intact higher brain centres via the vagus nerve, enables heart rate to increase in response to exercise (Takahashi et al., 2004; Wang et al., 2000). Individuals with higher injuries exhibit more sympathetic impairment (Hutzler, Ochana, Bolotin, & Kalina, 1998) and, unfortunately, withdrawal of parasympathetic influence on heart rate cannot match the sympathetic influence demonstrated in the able-bodied population. Therefore, individuals with cervical spinal cord injury demonstrate a heart rate plateau during exercise, resulting in limited cardiac output, limited oxygen transport and consumption, and limited exercise capacity (Birk, Nieshoff, Gray, Steeby, & Jablonski, 2001; Bravo, Guizar-Sahagun, Ibarra, Centurion, & Villalon, 2004). Peripheral limitations also confound acute responses, and limited availability of active muscle mass and decreased muscle pump activity are ultimately greater inhibitors of maximal capacity (Birk et al., 2001; Gass, Camp, Davis, Eager, & Grout, 1981; Hopman, Dueck, Monroe, Philips, & Skinner, 1998). Nevertheless, it is clear from the literature that 70–80% heart rate reserve is a benchmark training intensity for individuals with cervical spinal cord injury associated with meaningful improvement in cardiorespiratory fitness (Bizzarini et al., 2005; De Groot et al., 2003; Hooker & Wells, 1989; Whiting et al., 1983).

Peak responses for the current sample of competitive wheelchair rugby players are comparable with those in the literature. Goosey-Tolfrey and colleagues (Goosey-Tolfrey, Castle, & Webborn, 2006) reported a mean $\dot{V}O_{2peak}$ of 0.96 ± 0.17 litres $\cdot$ min^{-1} and a mean peak power output of 67.7 ± 16.2 W in a group of eight elite athletes with cervical spinal cord injury. Mean peak oxygen consumption was slightly higher and peak power output slightly lower in the current sample (Table II). These differences are quite minor and explained by the two additional participants with C5/6 injuries (lower power output) and additional participant with a C6/7 injury (higher oxygen consumption) in the current sample. Janssen et al. (2002) reported the most extensive normative evaluation for peak exercise performance among individuals with cervical spinal cord injury. Based on the physical capacity of 59 individuals with injuries from C4 to C8, Janssen and colleagues reported a mean $\dot{V}O_{2peak}$ of 0.90 ± 0.41 litres $\cdot$ min^{-1} and 12.6 ± 6.6 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}. Again, values for the current sample are consistent with these figures and the mean $\dot{V}O_{2peak}$ of the current sample would be evaluated as "good" based on the classification criteria reported by Janssen et al.

The results of this study indicate that wheelchair rugby participants can exercise at an intensity that elicits improvement in cardiorespiratory fitness, given appropriate design of training conditions, without clinician or therapist manipulation (i.e. sport setting). Thus, despite individuals with cervical spinal cord injury having fewer venues at which to participate in moderate to vigorous physical activity, participants in this sport may be able to achieve benefits of regular exercise, including improved quality of life and reduced risk of premature death, secondary disease, and obesity (Jacobs & Nash, 2004; Rimmer et al., 2004). This point is important because researchers now recommend varying exercise modes for individuals with spinal cord injury to reduce overuse injuries associated with continuous arm and wheelchair ergometry (Bizzarini et al., 2005; Figoni, 2003; Nash et al., 2007; Steadward, 1998). In general, training programmes for individuals with spinal cord injury typically result in a 10–20% improvement in $\dot{V}O_{2peak}$ and peak power output, even if the mechanisms are primarily through peripheral adaptations (Figoni, 2003). Thus although not all disability sport may enable a sufficient training stimulus for fitness improvement, evidence from the current study indicates that wheelchair rugby training may provide a sufficient stimulus to yield fitness improvements and so additional study is warranted.

Several limitations to the current study should be noted. First, there is some debate as to the most appropriate peak exercise protocol for this population. We used an arm ergometer to assess peak cardiovascular response, potentially limiting peak heart rate and over-estimating exercise intensity. Gass and Camp (1984) reported higher heart rate responses during wheelchair ergometry compared with arm ergometry among individuals with thoracic spinal cord injury but the expense of a wheelchair ergometer limits its use. Based on specificity, a wheelchair ergometer would have been a better choice; however, arm ergometry is the typical peak exercise protocol reported in training studies for individuals with cervical spinal cord injury (Bizzarini et al., 2005; De Groot et al., 2003). In addition, we used a continuous, rather than discontinuous, protocol with brief stages, which may have resulted in early muscular fatigue that limited the participants' ability to achieve a peak exercise response, thereby causing exercise intensities to be inflated. However, in a study of six males with spinal cord injury, Rasche and colleagues (Rasche, Janssen, van Oers, Hollander, & van der Woude, 1993) found that there was no difference in $\dot{V}O_{2peak}$ when comparing measures collected during a discontinuous protocol and those collected during a continuous protocol. Since the peak exercise responses of the current sample compare favourably to those of similar samples reported in the literature, we believe the identification of 70% heart rate reserve intensity is sound and that internal validity of time above threshold is strong. However, we would recommend longer stage duration (2 min) for future studies. Lastly, all nine of the participants with spinal cord injury experienced some degree of inhibition in sweating response, due to loss of autonomic nerve innervation, which impairs thermoregulation (Latzka, Pandolf, & Sawka, 1989). This lack of natural skin moisture during activity interfered with the heart rate monitor's ability to receive the electrical heart rate signal. As a result, there were times during activity when the heart rate monitor was unable to record the participants' heart rate. If more than 25% of the data for a particular activity condition was absent, the data for the participant during the specified activity condition was discarded, resulting in fewer data points for analysis. This criterion explains why one participant had only 2 days of data and another participant had only 1 day of data.

Conclusion

Individuals with cervical spinal cord injury were able to reach and sustain an exercise intensity associated with a meaningful improvement in cardiorespiratory fitness for approximately 40% of training time. Findings support the ability of wheelchair rugby training sessions to invoke a consistent, meaningful exercise load. It is also important to note that the athletes, regardless of functional ability, achieved and sustained training thresholds in a sport setting without clinician control of the exercise stimulus. This finding is a positive outcome for individuals facing multiple barriers to exercise and associated adaptations relative to cardiorespiratory improvement.

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