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Circuit resistance training in persons with complete paraplegia

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Abstract—*Background/Objective*: We assessed the metabolic and heart rate (HR) responses to a single session of circuit resistance training (CRT) in six subjects with complete paraplegia (T_5–T_{12} levels) in order to determine the caloric cost of the exercise. ***Methods***: Subjects underwent isoinertial weight training exercises with interspersed periods of high-cadence, low-resistance arm ergometry (AE). Following protocol familiarization, subjects completed one session of CRT during which continuous monitoring of HR, oxygen uptake (VO_2), and respiratory exchange ratio (RER = VCO_2/VO_2) was performed. Caloric cost was calculated from the exercise VO_2 values across the CRT session. A peak arm exercise test allowed data to be expressed as percentages of peak VO_2 and HR. ***Results***: Subjects displayed mean VO_2 values of 11.6 ± 2.4 ml/kg/min (mean ± SD) and a mean HR of 136 ± 17 beats/min across the CRT session, corresponding with 49.0% of peak VO_2 and 76.8% of peak HR. The RER values ranged from 0.96 to 1.19 and averaged above unity throughout the CRT session. ***Conclusion***: Despite the modest absolute VO_2 during exercise, CRT satisfies operational criteria developed for cardiorespiratory exercise prescriptions in persons without disability. The RER values recorded indicate that CRT is intense work that relies primarily on glycolytic metabolism.

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INTRODUCTION

Concerns for morbidity and mortality associated with the risk factors of sedentary behavior and hyperlipidemia have prompted many investigators to recommend including exercise in the daily activities of persons with spinal cord injury (SCI) if a healthy and active lifestyle is to be achieved or maintained (1–4). Individuals with SCI are known to be at elevated risk for cardiopulmonary complications as they age (5–7). Various reports have associated this risk with the sedentary lifestyle (8,9) and low levels of fitness (3,10) observed in persons with tetraplegia and paraplegia. In some cases their limited physical capacities are sufficient to compromise functional levels necessary for performance of basic daily activities (10). Atherogenic lipid profiles have also been observed in persons with chronic SCI (11–13), which have been attributed in persons without disability to sedentary lifestyles and low levels of fitness (8,14).

Cross-sectional and longitudinal studies confirm that persons with SCI benefit from exercise reconditioning through improved levels of fitness (1,3,4,15–17). Most of these studies have used arm ergometry (AE) or wheelchair locomotion as training modes, because they represent affordable and widely available equipment commonly used for successful physical conditioning.

However, as repetitive upper-limb movements are associated with shoulder injuries and degeneration (18,19), such exercises may ultimately hasten the upper-limb dysfunction reported in persons aging with SCI (20–23). While several exercise studies have attempted to strengthen the upper extremities of persons with paraplegia and to stabilize their shoulder girdle functions (24–27), relatively little is known of the acute responses to such exercise or the chronic benefits of strength training for persons with paraplegia. Also, while a considerable body of literature now guides clinicians in the prescription of strength and endurance exercise for persons without disability (28), the prescriptive process for professionals supervising exercise in persons with SCI is far more limited, and the hazards of their imprudent recommendations are far more serious.

We have recently reported benefits of increased upper-limb strength and endurance (29) and improved lipid profiles (30) that stemmed from an exercise training program that used resistance and endurance exercises for persons with paraplegia. The training protocol was modeled after programs of circuit resistance training (CRT) consisting of several resistance exercises performed in succession, with one set directly followed by a different resistance maneuver (31–33). Rest periods between these maneuvers are usually kept to a minimum, which keeps the HR elevated throughout the entire training session. The benefits of CRT in persons without disabilities are well established and include greater muscular strength and aerobic capacity than achieved when performing resistance training and/or aerobic training alone (33).

To date, an exercise prescription for persons with paraplegia that achieves the important benefits of increased endurance and strength has barely been examined. While recommendations for intensities of endurance and strength are sometimes derived from persons without disabilities (28), most of these guidelines are based upon lower-limb, not upper-limb, muscular performance. Conversely, limited guidelines have been established for persons with lower-limb paralysis who perform upper-limb work (34,35), although they are sometimes based upon testing of mixed populations of disabilities, including amputation and various neuromuscular disorders (35–37). Because persons with SCI have unique responses to upper-limb exercise resulting from vascular insufficiency of the lower extremities and varying degrees of adrenergic dysfunction (38–42), such prescriptions may not be appropriate in this population. Because the metabolic cost, cardiac responses, and caloric costs of CRT exercise in paraplegics have not been measured during CRT exercise, but have undergone such necessary evaluation for others undergoing circuit exercise (43–46), we studied these acute responses during a typical exercise bout in subjects habituated to the exercise. We then examined whether they were consistent with established guidelines commonly used for recommending exercise training intensities (28,47,48).

METHODS

Subjects

Six men with neurologically complete paraplegia at T_5 through T_{12} volunteered to participate in this study. The T_4 level was designated as the highest lesion accepted for inclusion in this study, because persons with SCI at or below this level of injury experience both competent and homogeneous cardiovascular sympathetic drive (49,50). The International Standards for Neurological Classification (51) were used as the authority for establishing levels and completeness of injuries. Study participants had completed 12 weeks of intense CRT training immediately before this study. Subjects appeared in good health and without medical histories of shoulder joint dysfunction. The absence of cardiac contraindications to exercise was established by graded arm exercise testing with 12-lead electrocardiography (EKG) monitoring. Consent to participate in the study was obtained in accordance with, and approval of, the Medical Sciences Subcommittee for the Protection of Human Subjects. Descriptive characteristics of the subjects are shown in **Table 1**.

Peak Cardiorespiratory Testing

Peak AE was performed within 2 to 7 days of CRT testing. Subjects refrained from consumption of food, caffeine, nicotine, and alcohol prior to exercise testing. Peak cardiorespiratory tests were performed on an Upper Body Ergometer (Cybex UBE, Cybex International, Medway, WA) with the use of a previously described incremental protocol (29). Briefly, subjects propelled the ergometer at a constant cadence of 60 rpm. The initial 3-minute workload was performed at 400 kpm and thereafter increased by 100 kpm for each 3-minute stage. The test was stopped at the point of volitional exhaustion or when

Table 1.
Descriptive characteristics of study participants.

Subject	Age (yr)	Weight (kg)	Level of Injury	Duration of Injury (yr)
1	43.0	59.7	T_{10}	5.0
2	43.0	78.6	T_6	14.3
3	46.3	97.9	T_{12}	3.5
4	24.9	64.5	T_5	7.4
5	33.1	82.7	T_6	5.0
6	23.8	92.0	T_{10}	0.6
Mean	35.7	79.2	—	6.0
SD	9.8	15.0	—	4.7

subjects were unable to maintain the assigned workload. Termination points for the test followed the Guidelines for Exercise Testing and Training of the American College of Sports Medicine (5th edition) (28). Metabolic and cardiac responses to exercise were continuously monitored via open-circuit spirometry (Sensormedics Horizon System, Yorba Linda, CA) and 12-lead EKG (FX-406U Cardimax; Fukuda Denshi; Tokyo, Japan), respectively.

Circuit Resistance Training: Training Protocol

Subjects were habituated to the CRT protocol (29) during at least 12 weeks of exercise conducted three times weekly on nonconsecutive days. Exercise time for each CRT session was approximately 40 to 45 minutes and consisted of isoinertial resistance exercise interspersed with periods of high-cadence, low-resistance AE. Isoinertial resistance movements were performed on an Equalizer 7000 Multi-Station Exercise System (Helm; Bozeman, MT) specifically designed for wheelchair users. The following resistance exercises were performed by the subjects seated in their wheelchairs: Pair 1: (a) Military press: shoulder abduction with scapular elevation and upward rotation and (b) Horizontal rows: shoulder horizontal abduction with scapular adduction, Pair 2: (a) Pec dec: shoulder horizontal adduction and (b) Preacher curls: elbow flexion supported on an incline pad, Pair 3: (a) Wide grip latisimus pulldown: shoulder adduction with scapular downward rotation and depression and (b) Seated dips: shoulder flexion, scapular depression and elbow extension.

Each pair of resistance exercises was preceded by 2 minutes of AE with the use of a Saratoga Cycle arm ergometer (Fort Collins, CO). Subjects then performed ten slow, controlled repetitions of the first resistance exercise (military press) each lasting 6 seconds (3 seconds concentric, 3 seconds eccentric), followed immediately by ten repetitions of horizontal rowing. Subjects then changed stations and performed 2 minutes of high-cadence, low-resistance AE. Subjects quickly wheeled to the next pair of resistance stations and performed the second pair of maneuvers (pec dec and preacher curls) as previously described, followed by 2 more minutes of high-intensity AE. Subjects then completed the third and final pair of resistance exercises (latisimus pulldown and seated dips) followed by 2 more minutes of high-intensity AE. These nine maneuvers (six isoinertial resistance exercises and three bouts of AE) comprised one full circuit. Each CRT session consisted of three of these circuits performed without interruption. The recovery periods between stations were minimal (15 to 20 seconds) and were limited to the time needed for subjects to wheel to the next station.

Resistive loads used during the 12-week training period were set between 50 to 60 percent of the one repetition maximum (1RM) strength and were recomputed every 4 weeks for each resistance exercise. One repetition strength was calculated with the Mayhew regression equation (52):

$$1RM = Wt/\,(0.533 + \,0.419e^{-0.055*reps}),$$

where “1RM” is the calculated one repetition maximum, “Wt” is the resistance used in the last set where three ≤ repetitions ≤ eight, and “reps” is the number of repetitions completed in the last set. A detailed progression of resistance settings during 12 weeks of training has been described elsewhere (29,30).

Circuit Resistance Training: Testing Protocol

Metabolic and cardiac responses were measured during a single-test session of CRT. Subjects refrained from consuming food, caffeine, and nicotine 4 hours before testing. They also refrained from ingestion of alcohol and the performance of strenuous activity for 24 hours before testing. Subjects performed all usual maneuvers during this single session as described in the previous section. Resistance settings were set at 60 percent of the 1RM. Metabolic activity for VO_2, V_E, and RER (respiratory exchange ratio) during CRT exercise was continuously monitored via open-circuit spirometry (Sensormedics

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Horizon System, Yorba Linda, CA). Heart rate (HR) was continuously recorded with the use of a three-lead portable EKG using a CM5 bipolar lead configuration (Miniscope MS-3, Shiller AG, Baar, Switzerland). Caloric expenditure was estimated from the VO_2 as follows:

$$1L\ O_2 \cong 5\ Kcal^{28}.$$

Data Analysis

Cardiorespiratory and HR data were expressed within intervals and across the entire exercise session as mean ± SD. Data were expressed as both absolute responses and as a percentage of VO_{2peak} and HR_{peak}.

RESULTS

Metabolic responses of the subjects to peak AE tests are shown in **Table 2**. Subjects attained peak power outputs ranging from 500 to 900 kpm, with an average power output at peak effort of 717 ± 147 kpm (mean ± SD). The average VO_{2peak} was 23.68 ± 2.95 ml/kg/min and the mean peak HR 178 ± 15 beats/min, both attained at a peak exercise RER of 1.14 ± 0.03.

Metabolic responses monitored during the first two cycles of the circuit are shown in **Table 3**. The highest mean VO_2 and HR values attained during any exercise interval were 14.7 ± 2.5 ml/kg/min and 148 ± 24 beats/min, respectively. When averaged across the entire exercise bout, the mean VO_2 was 11.6 ± 2.4 ml/kg/min and the mean HR was 136 ± 17 beats/min, which corresponded with 49.0 percent of the VO_{2peak} and with 76.8 percent of the HR_{peak}. Heart rate responses varied among maneuvers from a low of 66.1 ± 8.3 percent to a high of 83.0 ± 11.1 percent peak. A distinct metabolic drift from the first to second cycle for both VO_2 and HR was evident.

Table 2.
Peak physiological responses to graded arm ergonometry in six subjects with paraplegia (mean ± SD).

Subject	Heart Rate (beats /min)	Power Output (kpm)	VO_2 (L/min)	VO_2 (ml/kg/min)	RER
1	182	600	1.661	27.83	1.18
2	188	700	2.076	26.41	1.16
3	174	500	2.191	22.38	1.08
4	188	800	1.483	22.99	1.14
5	150	800	1.629	19.69	1.12
6	188	900	2.098	22.8	1.13
Mean	178	717	1.86	23.68	1.14
SD	15	147	0.30	2.95	0.03

The caloric cost of exercise computed from the measured levels of VO_2 averaged 170 kcal for the six subjects. RER values ranged from 0.96 ± 0.12 to 1.19 ± 0.11, reflecting high reliance on glycogen fuel substrates and anaerobic metabolism.

DISCUSSION

Various research strategies have been used to define and refine the exercise prescription used for endurance training of persons without disabilities (28,47,48). In most cases these studies have tested various combinations of acute exercise intensities, durations, and frequencies to examine whether they ultimately improved cardiorespiratory endurance. These studies with the general population have allowed scientists and clinicians to prospectively assign similar exercise criteria to other groups and then to examine for comparable conditioning effects. The current study was based upon a different strategy similar to that previously reported (43), which examined the acute responses to an exercise conditioning program already shown successful at increasing the upper-limb endurance and muscle strength of persons with paraplegia. This strategy was employed for several reasons. First, it circumvented the trial-and-error method of examining training effects based upon possible overestimation or underestimation of prescriptive combinations that include training frequency, intensity, duration, and mode. Second, most exercise conditioning programming for persons with paraplegia is based upon training intensities derived from studies of persons without disability performing either lower or upper-limb exercise (28,34,35,47). Prescriptive errors should be anticipated when such guidelines are used for persons with paraplegia, because they usually use their arms not their legs to perform work and have a physiological response to upper-limb exertion differing significantly from persons with intact neuraxes (27,38,39,41,50).

The findings of the current study represent the first report of acute responses to CRT in persons with

Table 3.
Acute cardiorespiratory responses to exercise maneuvers during a single session of CRT in subjects with paraplegia (n = 6, mean ± SD).

Maneuver		Cycle 1 of CRT Session			Cycle 2 of CRT Session		
		HR (bpm)	VO_2 (ml/kg/min)	RER	HR (bmp)	VO_2 (ml/kg/min)	RER
Arm Ergometry	Mean	117	10.90	0.96	138	13.44	1.04
	SD	4	2.09	0.12	18	2.59	0.07
Military Press	Mean	125	8.73	1.05	143	12.35	1.05
	SD	13	1.53	0.16	21	1.77	0.11
Horizontal Rows	Mean	123	9.47	1.19	143	10.77	1.15
	SD	11	1.46	0.11	18	2.17	0.08
Arm Ergometry	Mean	129	13.60	1.15	148	14.66	1.07
	SD	11	1.83	0.11	20	2.52	0.07
Pec Dec	Mean	134	11.52	1.08	148	12.16	1.07
	SD	14	3.39	0.09	24	3.56	0.08
Preacher Curls	Mean	130	9.04	1.13	143	10.82	1.11
	SD	12	2.03	0.15	19	3.92	0.07
Arm Ergometry	Mean	131	13.29	1.04	143	13.54	1.02
	SD	19	2.66	0.11	20	2.23	0.08
Latisimus Pulldown	Mean	136	11.36	0.98	145	10.37	0.97
	SD	21	3.27	0.08	21	1.92	0.08
Seated Dips	Mean	139	11.65	1.07	140	11.03	1.00
	SD	16	2.96	0.11	20	2.09	0.09

paraplegia. To our knowledge, not one of the studies examining strength training in this population has measured the physiological costs of that work or has sought to empirically explain their strategies for design of the exercise algorithm (24–26). In the current program design, we used alternating sets of resistance exercises with intensities of 50 to 60 percent of the 1RM, similar to that used on other CRT programs (31), and high-cadence, low-resistance AE. The physiological response necessary to support this exercise was 49 percent of the subjects' VO_{2peak} and 76.8 percent of their HR_{peak}. By comparison, typical recommendations for exercise prescription for persons without disability range from 50 to 85 percent of VO_{2max} and 60 to 90 percent of HR_{max} (28). Thus, values for HR response to CRT exercise were in the middle of the prescribed ranges, while the mean VO_2 response was near the lower end of the range.

A recent study from our laboratory observed that 12 weeks of CRT significantly increased muscular strength and cardiorespiratory endurance in persons with complete paraplegia (29,30). Subjects participating in the trial increased their VO_{2peak} by 29.7 percent, time to fatigue by 30.8 percent, and peak power output by 16.1 percent. Significant increases in upper-limb isoinertial muscular strength ranged from 11.9 to 30 percent, depending upon the maneuver. Also, significant increases in isokinetic strength were observed for shoulder joint internal rotation, abduction, adduction, extension, and horizontal adduction. The design of the program was based upon previous CRT programs performed in healthy persons and those with Type I diabetes, in which both increased muscle strength and cardiorespiratory endurance ensued (31). It appears that CRT has adequate intensity to bring about long-term cardiorespiratory benefits, as well as increased isoinertial and isokinetic muscular strength in persons with complete paraplegia.

It has been previously reported that exercise in persons with paraplegia needs to be performed at the upper ranges of the recommendations for the general population (80 to 85 percent VO_{2peak}) in order to elicit training effects (16). The current findings challenge the necessity for training with such high VO_2 intensities, as has been reported by others (43), and suggest that choice of training mode may be critical. It is important to note that most of the exercise studies previously performed in persons with SCI have used continuous endurance protocols, as contrasted with the interval nature used in the present study. Not surprisingly, RER values during CRT, which ranged from 0.96 ± 0.12 to 1.19 ± 0.11, indicate that these individuals were performing high-intensity work throughout the entire CRT session.

The findings of the present study are quite similar to those of several prior investigations involving circuit weight training (CWT) in persons without disability (53–55). In those studies, the HR and VO_2 responses of nondisabled men and women were assessed during CWT consisting of resistance exercises separated by rest periods up to 30 seconds in length. As in the present study, those absolute physiological responses were computed relative to the subjects' maximal responses. The HR responses to CWT ranged among these studies from 67 to 74 percent of the HR_{max} values of the subjects without disability. However, those subjects reached mean levels of oxygen uptake equivalent to only 39 to 49 percent VO_{2max}. High-lactate measures collected as part of the assessment procedure (e.g., 145 mg/100 ml) allowed those authors to conclude that CWT is highly anaerobic in nature, hence limiting the resistance used in their protocol to 40 to 50 percent of 1RM. The protocol of the present study included 2-minute intervals of high-cadence, low-resistance AE, which subjects reported as having a flushing effect on the ischemic sensations often associated with CWT. The addition of arm cranking with low resistance may have allowed the use of greater resistance in the current CRT investigation (up to 60 percent 1RM) with mean HR responses similar to and VO_2 responses greater than most of those reported with discontinuous CWT protocols.

One of the most interesting findings of this study was the caloric expenditure of the exercise bout, which averaged 170 kcal per 40-minute session of CRT. This expenditure is lower than usually reported in exercise training programs (45,56,57), and (when performed three times weekly) below the caloric expenditure of 1,000 kcal generally thought to be the threshold of caloric expenditure necessary to alter blood lipid profiles (57). In several studies, the per session caloric expenditure required to improve lipid profiles and achieve a training effect was more than double (350 kcal/session) that expended by subjects in this study (45,56,56). Several factors may explain these apparent paradoxes. First, the low VO_2 achieved during CRT may indicate the normal response to resistance exercise training in persons without disability who achieve a lower VO_2 relative to HR response than observed during dynamic endurance exercises, including treadmill running or leg cycling (40,50). Second, the caloric expenditure reported in this study reflects the oxygen consumed during, not after completion of, exercise. It is known that an excess postexercise oxygen consumption (EPOC) accompanies acute exercise (59–61) and that higher intensity work may evoke a lower VO_2 response during, but greater VO_2 response in, the periods following exercise (44). This has been reported in persons undergoing CRT, for whom a greater EPOC is shown in protocols having limited rest periods between resistance maneuvers (44). Third, HR is commonly used as an index of work intensity in persons with normal chronotropic responses to work as the HR-VO_2 relationship is linear throughout the range of submaximal work intensities (62,63). By contrast, persons with paraplegia have a higher HR response to work than persons without paraplegia performing work at the same absolute exercise intensity (27,38,50). Thus, work intensities may be overestimated in persons with disability when HR is used to prescribe the intensity of work, for which caution must be exercised. In the current study, the AE was performed without applied resistance, a state not tested by other studies but obviously successful at maintaining the intensity of work performed during resistance maneuvers.

CONCLUSIONS

Subjects with paraplegia undergoing CRT perform acute exercise at 49 percent of their VO_{2peak} and 76.8 percent of their HR_{peak}. An intensity based upon this VO_2 would be at the lowest limit of established criteria used to target increased cardiorespiratory endurance but at the midrange of the HR recommendations. Circuit resistance exercise favors glycolytic metabolism as evidenced by mean RER greater than unity, which is consistent with the performance of resistance exercises. Caloric expenditure is modest during exercise and representative of physiological responses for persons without SCI to CRT exercise, although measurement of EPOC is indicated to determine caloric contributions of oxygen consumed after cessation of work.

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