Acute energy cost of multi-modal activity-based therapy in persons with spinal cord injury

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Objective: To examine acute energy costs of multi-modal activity-based therapy (ABT) in men and women with spinal cord injury (SCI).
Study design: Descriptive case series.
Setting: An outpatient center in California.
Participants: Seven men and women (age = 28.3 ± 11.6 years; duration of injury = 4.3 ± 2.5 years) with injury levels ranging from C5 to T8.
Intervention: Activity-based therapy.
Outcome measures: Oxygen uptake (VO_2), energy expenditure (kcal/minute), SCI Metabolic Equivalent of Task (MET) (1 MET = 2.7 ml/kg/minute).
Results: Oxygen uptake (VO_2) during ABT ranged from 5.10 to 8.62 ml/kg/minute, with VO_2 consistently higher during modalities involving load bearing versus non-load bearing ($P = 0.08$). SCI MET values ranged from 1.89 to 3.24 and were significantly higher in subjects with mid-thoracic injury versus low-cervical injury ($P = 0.01$).
Conclusion: Data reveal that multi-modal ABT increases VO_2 in persons with SCI, but energy expenditure is relatively low. Strategies must be identified to optimize energy expenditure in the SCI to reduce health risks. Modalities involving load bearing seem to be superior to non-load-bearing activities. VO_2 was greater in response to load-bearing modalities than non-load-bearing modalities. It remains to be determined whether chronic ABT enhances cardiovascular fitness and reduces disease risks in this population.

Keywords: Activity-based therapy, Spinal cord injuries, Rehabilitation, Paraplegia, Tetraplegia, Energy expenditure, MET, Resistance training, Ergometry, Functional electrical stimulation, Assisted standing

Introduction

Approximately, 12 000 spinal cord injuries (SCIs) occur annually, with 80% of injuries occurring in men.[1] Onset of SCI often reduces participation in physical activity and is consequent with alterations in endocrine function, body composition, and vitality.[2] One result of reduced physical activity is the increased incidence of obesity that contributes to enhanced risk of cardiovascular disease and diabetes.[3–5] Consequently, effective rehabilitation is needed in persons with SCI to reduce the severity of co-morbidities associated with SCI.

Initially, the primary modality used to rehabilitate persons with SCI was arm ergometry as it targets the arms, which are needed for day-to-day wheelchair operation, and promotes increases in aerobic fitness.[6] As early as 1989, studies were published revealing changes in VO_2 in response to acute functional electrical stimulation (FES) and/or hybrid FES-training/rowing in persons with SCI. FES is a practical therapy in this population as it minimizes excess strain on the upper extremities while activating the paralyzed musculature to stimulate hypertrophy, improve circulation, and enhance aerobic fitness.[7,8] Mean VO_2 during FES widely varies across individuals, ranging from 0.57 l/minute in persons with injury at C4–T10 to 2.12 l/minute in males with thoracic injury.[9,10] Another popular modality is resistance training, as it augments muscular strength in this population.[11] For example, Nash *et al.*[12] reported that circuit training increased energy expenditure to values approximating 40%VO_2 max in 17 individuals with complete injury (T4–L1). Finally, locomotor training in the form of body weight-supported treadmill training has been applied

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in this population to improve functional capacity and enhance muscle mass.[13,14] Overall, these modalities are effective to improve physical function and reduce morbidity in persons with SCI.

Recently, activity-based therapy (ABT) has become a popular modality to treat persons with SCI at facilities across the world. This mode of therapy consists of the following components: patterned motor activation via locomotor training and/or FES, patterned and non-patterned activation through task-specific rehabilitation and strengthening, including circuit and/or resistance training, and sensory stimulation through sensorimotor therapy.[15] It is unique from traditional therapies in that it does not focus on teaching compensatory techniques, but targets recovery of neural function. The primary goal of this therapy is to promote recovery of motor and sensory function below the injury location.[15,16] Preliminary data show that ABT promotes neural recovery in rats completing gait training as well as increases cardiovascular fitness in persons with SCI performing FES.[17,18] Nevertheless, acute physiological responses to ABT consisting of multiple exercise modalities are not well documented.

The primary aim of this study was to examine acute responses to multi-modal ABT in men and women with SCI and to use this information to begin to build a database of energy costs for these activities. The treatment modalities included in this research were employed in studies showing greater bone mineral density and lean body mass, increased lower-extremity strength, and improved ($P < 0.05$) motor function in men and women with SCI after 6 months of training.[16,19,20] Collins *et al.*[21] recently published a compendium of energy cost requirements of various physical activities and activities of daily living for individuals with SCI, and this study may help to expand upon these findings.

Methods

Subjects

Participants in this study included seven men and women with SCI. They were categorized by neurological injury location either low tetraplegia (C5–C8) or mid-thoracic (T1–T8). Their demographic characteristics are shown in Table 1. There were no differences ($P > 0.05$) in any characteristic between groups. Due to the small sample size, motor complete- and motor incomplete injuries, defined through the American Spinal Injury Association Impairment Scale (AIS) as A or B (motor complete) and C or D (incomplete), were combined. Subjects were currently completing rehabilitation 2–3 days/week at a facility in Southern California. Participants were free of known cardiac, pulmonary, or metabolic disease, and were not on medications that affect cardiovascular or metabolic function. Subjects filled out a health history questionnaire and provided informed consent before participating in the study. All experimental procedures were approved by the University Institutional Review Board. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Table 1 Demographic characteristics of subjects

	Upper-level injury (C5–C8)	Mid-level injury (T1–T8)
Sample size (*n*)	3	4
Age (year)	28.0 ± 14.8	28.4 ± 11.0
Height (cm)	183.3 ± 14.2	178.7 ± 12.8
Mass (kg)	74.3 ± 20.5	76.2 ± 19.3
Injury duration (year)	4.7 ± 2.9	3.5 ± 2.5
Male/female	2/1	3/1
Motor complete/motor Incomplete	2/1	3/1

Values are mean ± standard deviation.
No statistical difference between groups ($P > 0.05$).

Design

Subjects refrained from exercise for 24 hours prior to the session and were 2 hours post-absorptive. They completed a 2–3-hour session of ABT, during which expired air via indirect calorimetry was continuously obtained. All activities were supervised by trained personnel.

Exercise protocol

ABT as completed in this study included the following modalities:

1. Active assistive exercise: While in a supine or prone position, the subjects' limbs were assisted through different ranges of motion and provided a resistance less than gravity. The subjects were instructed to attempt or visualize actively assisting or resisting the movement performed.
2. Standing/standing frame (Easystand Evolv, Altimate Medical, Morton, MN, USA): The subject was raised into, or if able, raised themselves into a standing position to load the lower extremities. While in this position, the subject performed various lower- and upper-body extremity exercises to exhaustion.
3. Total gym (EFI Inc., San Diego, CA, USA): Subjects completed active and/or active assistive squat exercises while loading the lower extremities at 65% of body weight.
4. Hands and knees/kneeling: Subjects were placed on the floor with the knees and hips flexed 90°, the shoulder flexed 90°, and the elbow extended 180° so that body weight is evenly distributed between the upper and lower body (Fig. 1A). During kneeling, subjects were

placed on the floor with the knees flexed 90° and the hips extended 180° so that body weight is supported by the lower body (Fig. 1B). Various upper- and lower-body movements were performed in this position.

5. Spin bike: The subject was seated on a modified stationary bike (V-Bike, Star Trac, Irvine, CA, USA) with a 22 kg fly wheel. The modifications included a wider seat and a back support and, if necessary for the person with tetraplegia, a platform walker was used in place of the standard handle bars (Figs 2A and B). Load bearing occurred through the upper limbs (Figs 2C and D). The subject attempted to pedal the bike under his/her own power; if unable to do so, the subject was assisted by staff to complete the movement.
6. FES leg ergometry (Restorative Therapies, Baltimore, MD, USA): While seated in a wheelchair, the subjects' gluteus maximus, hamstrings, and quadriceps muscles were stimulated with surface electrodes at 140 mA, with a pulse width of 250 μs at a frequency equal to 33.3 Hz. Ergometer control speed was set at 45 rpm with a resistance of 1.00 Nm.

Participants completed an average of four of these modalities during a single day of training. A base sequence was implemented that consisted of active assistive exercise first, followed by load-bearing exercises, and finishing with FES. The sequence and incorporation of the different load-bearing modes were different across subjects due to different levels of physical function and injury location. With the exception of FES, all modalities were performed at an intensity that the subjects considered was their maximum effort for the duration of the exercise. Approximately 5–15 minutes recovery was provided between exercises to allow subjects to rest, transfer to the next modality, and drink water *ad libitum*. During recovery, the respiratory mask was removed. Gas exchange data were continuously obtained during each modality, which lasted a minimum of 8 minutes to achieve a steady state.

Assessment of gas exchange data

A portable metabolic cart (Jaeger OxyCon, Viasys HealthCare, Yorba Linda, CA, USA) was used to acquire breath-by-breath gas exchange data throughout exercise. Initially, the device was calibrated to room air as well as a standard gas mixture equal to 16.0% O_2 and 4.0% CO_2. A vest was placed on participants' chest containing the gas analyzers and flow turbine, and a respiratory mask was used to collect expired air. VO_2 (in ml/kg/minute and ml/minute) was time-averaged every 30 seconds during exercise and used to calculate energy expenditure (in kcal/minute) using respiratory exchange ratio as well as in METs, using the constant proposed by Collins *et al.*[21] for SCI where 1 MET = 2.7 ml/kg/minute (SCI MET).

Statistical analysis

Data were analyzed using JMP (SAS, Cary, NC, USA) for normality of distribution using the Shapiro–Wilk test. Normally distributed data were tested using the matched-pairs *t*-test, and non-parametric statistics (Wilcoxon rank-sum) were used on non-normal data. Both were used to determine if there were significant differences in sample characteristics and measured parameters between injury-level categories. All analyses were two-tailed, with alpha = 0.05. Data are reported as mean ± standard deviation where applicable.

Figure 1 (A) Hands and knees, during which subjects were placed on the floor and required to support their body weight through the upper and lower extremities while performing various upper- and lower-body exercises. (B) Kneeling, during which subjects were placed on the floor and required to support their body weight through the lower extremities while performing various upper- and lower-body exercises.

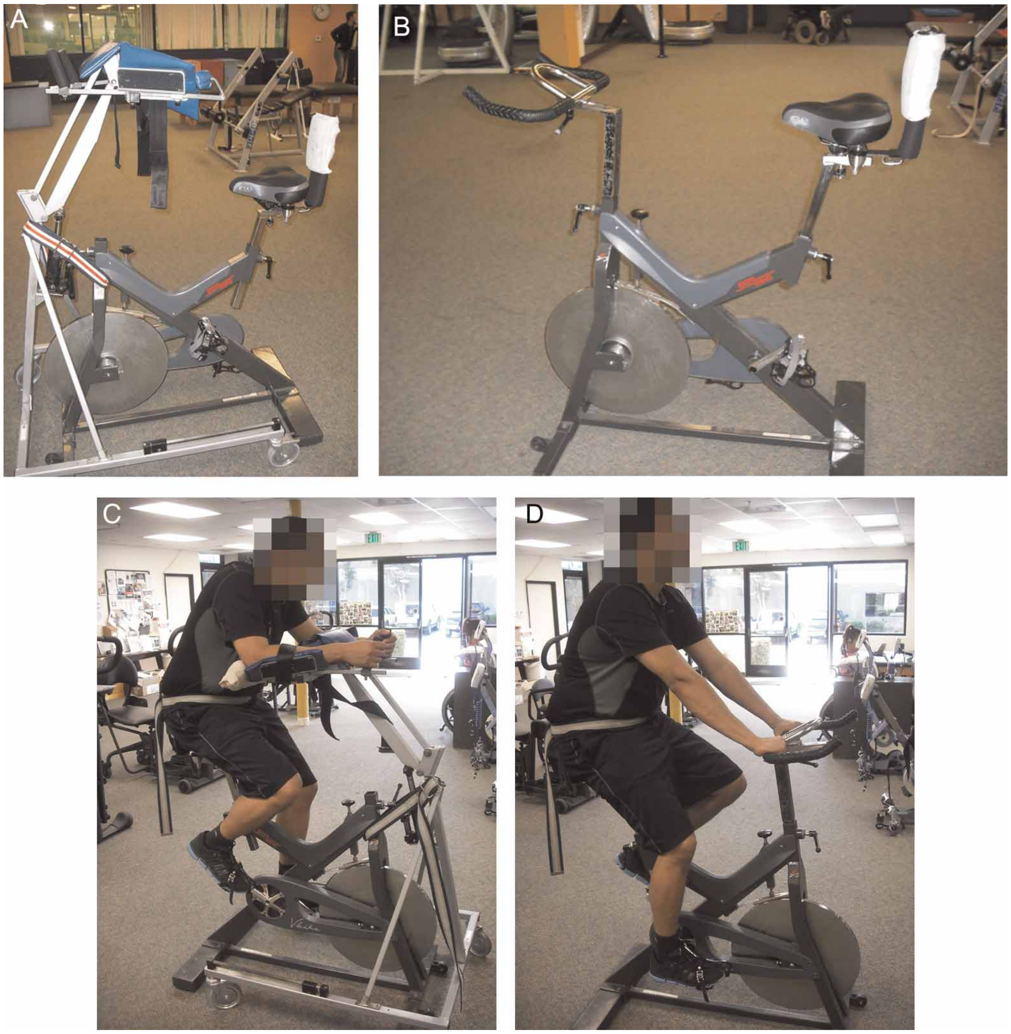

Figure 2 (A) Spin bike, Low cervical set up, platform walker secured in place of handle bars, upper extremities were loaded through placement of forearms on the walker. (B) Spin bike, Mid-thoracic set up, upper extremities were loaded through placement of the hands on the handle bars. (C) Spin bike, Low cervical set up showing subject positioning. (D) Spin bike, Mid-thoracic set up showing subject positioning.

Results

Due to the heterogeneity of those with SCI (i.e. variations in injury level, existing motor and sensory function, and response to treatment), the selection of specific modalities within ABT programs is very individualized and is performed to best take advantage of the functional abilities of each client. As participants varied with regard to injury level, injury duration, and physical functioning, they did not complete identical exercise programs during the study. This also required that exercises be performed in a manner and sequence that were most advantageous to the individual in that session. We believe that it was important to capture this aspect; therefore, data were recorded throughout each modality during each exercise session. This may present a more realistic representation of the actual energy costs of these activities. Consequently, data are presented for six activities that were performed by at least two subjects in a single-injury category.

VO_2 and energy expenditure data

Oxygen uptake (ml/kg/minute and ml/minute), energy expenditure (kcal/minute), and SCI MET equivalents for each modality are presented in Table 2. VO_2 and calorie expenditure during exercise were consistently lower in subjects with low cervical injury versus those with mid-thoracic injury. Modalities providing skeletal loading in subjects with mid-thoracic injuries (standing/standing frame, total gym, and spin bike) tended to reveal greater oxygen consumption than modalities in which subjects were seated or lying down (FES and active assistive exercise) ($P = 0.08$). VO_2 during standing/standing frame was significantly higher in subjects

Table 2 Energy expenditure during acute ABT

Activity-injury group	*n*	VO_2 (ml/minute)	Kcal/minute	VO_2 (ml/kg/minute)	SCI MET
Active assistive exercise					
C5–C8	2	411.74 ± 80.51	2.00 ± 0.40	5.10 ± 1.92	1.89
T1–T8	4	471.12 ± 199.57	2.29 ± 0.97	6.08 ± 1.75	2.25
Standing/standing frame					
C5–C8	3	391.74 ± 36.86*	1.90 ± 0.18	5.54 ± 1.56*	2.05
T1–T8	4	655.56 ± 178.65	3.18 ± 0.87	8.62 ± 0.77	3.19
Total gym					
C5–C8	2	422.39 ± 8.45	2.05 ± 0.04	5.13 ± 1.07	1.90
T1–T8	3	551.61 ± 166.18	2.67 ± 0.83	7.01 ± 0.72	2.60
Hands and knees/kneeling					
C5–C8	2	387.60 ± 23.19	1.95 ± 0.01	6.45 ± 1.37	2.39
Spin bike					
C5–C8	3	387.11 ± 76.73	1.88 ± 0.37	5.57 ± 2.35	2.06
T1–T8	2	595.05 ± 160.09	2.89 ± 0.78	8.76 ± 0.12	3.24
FES leg ergometry					
T1–T8	3	559.10 ± 30.91	2.71 ± 0.15	6.84 ± 0.96	2.53

Values are mean ± standard deviation.
FES, functional electrical stimulation; SCI MET, 2.7 ml/kg/minute.
*$P < 0.05$ between groups for this modality.

with mid-thoracic injuries than those with low cervical injuries ($P = 0.03$; Table 2).

Discussion

The primary aim of this study was to describe the energy cost of acute multi-modal ABT in persons with SCI. Results revealed that prolonged bouts of ABT increased VO_2 with magnitude of these increases higher in individuals with mid-thoracic compared to low cervical injury. Standing demonstrated the highest VO_2 in participants with mid-thoracic injuries, with values similar to those reported for wheelchair ambulation, FES-cycling, and arm ergometry, yet greater than observed with circuit training.[6,12,22,23]

The energy expenditure and VO_2 reported in the present study differ somewhat from previously demonstrated values. Results from Perret *et al.*[24] revealed higher mean calorie expenditure equal to 4.8 kcal/minute during 60 minutes of FES in men and women with complete thoracic injury. This population, however, did not include men and women with cervical injury who tend to reveal lower exercise tolerance than persons with a thoracic/lumbar-level injury.

In the Collins *et al.*[21] compendium of energy cost requirements for individuals with SCI, subjects in the low cervical and mid-thoracic groups exhibited higher energy cost during arm cranking at 32–96 W and wheelchair ambulation (2.60–6.33 SCI METs) compared to activities including aerobics, circuit training, and weight training (1.83–3.41 SCI METs). However, no values were reported for rehabilitation-type exercises including active assistive exercise, FES, and other ABT modalities as presented in the current study. SCI METs for these activities range from 1.89 to 3.24, which is comparable to traditional exercise including aerobics, circuit training, and weight lifting. The one activity included in Collins *et al.*[21] which is similar to that presented here was 'assisted standing'. In persons with lower-level thoracic injuries (T9–L4), an oxygen uptake, energy expenditure, and SCI MET cost equal to 238.0 ± 5.7 ml/minute, 1.23 ± 0.03 kcal/minute, and 1.17 MET cost were reported. All subjects in the present study exhibited higher values for these parameters during standing/standing frame exercise (Table 2), which could be explained by the greater familiarity of our subjects with this exercise modality and the need to perform other exercises while in this position, including isolated upper-extremity movements and assisted squats, which require additional active muscle mass and thus oxygen uptake.

It has been recommended for persons with SCI to expend 1000–2200 kcal/week to reduce disease risks.[25] Perret *et al.*[24] showed that 4–8 hours/week of FES is adequate to meet this criterion. However, our results show lower energy expenditure for multi-modal ABT ranging from 1.88 to 3.18 kcal/minute, which would require between 5.2 and 8.9 hours of activity per week to expend this amount of calories. It is plausible that exercise that activates a large muscle mass, such as FES or standing, should be emphasized in rehabilitation regimens to optimize calorie expenditure and potentially reduce health risks, as greater durations of exercise may be contraindicated in this population due to lack of adherence, increased injury risk, or simply lack of feasibility. Identifying suitable exercise regimens in patients with cervical injury is needed too, as their lower physical function reduces calorie expenditure and thus their ability to meet this standard.

This study faced a few limitations. First, data can only be applied to men and women with SCI completing ABT and not arm ergometry, athletics, or activities of daily living. Second, subjects had chronic SCI, and so their responses cannot be compared with responses of persons with acute or sub-acute injury (<6 months post-injury). Participants' VO_2 max was not obtained, and so it is unknown as to what fraction of maximal aerobic power subjects were exercising. In addition, participants typically exercised at a self-imposed maximum, and so data may represent sub-maximal effort. Finally, the number of females participating in the study was small, which limits its generalizability to the entire female population.

Conclusion

The types of exercise modalities employed in the present study are gaining prominence in the field of SCI rehabilitation due to their promotion of functional recovery below the neurological injury level.[15,16] Considering the low levels of physical fitness in persons with SCI and consequent enhanced risks of chronic disease, identifying calorie expenditure for ABT modalities and subsequently educating clientele with regard to meeting minimum duration of these activities seems paramount to reduce morbidity and mortality in this population. The current report is a first step in understanding the acute physiological responses to acute ABT and may allow clinicians to better match participants' caloric intake to expenditure. Further study is merited to examine the effects of chronic ABT on cardiorespiratory fitness, muscular function, and disease prevention in persons with SCI.

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