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ORIGINAL RESEARCH

Energy Expenditure and Heart Rate Responses to Increased Loading in Individuals With Motor Complete Spinal Cord Injury Performing Body Weight—Supported Exercises

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Abstract

Objective: To examine acute metabolic and heart rate responses in individuals with motor complete spinal cord injury (SCI) during stepping and standing with body weight support (BWS).

Design: Cohort study.

Setting: Therapeutic exercise research laboratory.

Participants: Nonambulatory individuals with chronic, motor complete SCI between T5 and T12 (n=8) and healthy, able-bodied controls (n=8).

Intervention: Not applicable.

Main Outcome Measures: Oxygen consumption ($\dot{V}O_2$) and heart rate.

Results: Individuals with motor complete SCI performed standing and stepping exercises in a BWS system with manual assistance of lower body kinematics. $\dot{V}O_2$ and heart rate responses were assessed in relation to level of BWS. Weight support was provided by an overhead lift at high (≥50% BWS) or low (20%−35% BWS) levels during stepping and standing. Although participants with motor complete SCI were unable to stand or step without assistance, levels of $\dot{V}O_2$ and heart rate were elevated by 38% and 37%, respectively, when load was maximized during stepping (ie, low BWS). Participants without an SCI (able-bodied group) had a similar acute response to exercise. None of the participants met the target range for $\dot{V}O_2$ response in any of the tasks. However, stepping was sufficient to enable half of the participants in the SCI group to attain the target range for heart rate response to exercise.

Conclusions: Individuals with motor complete SCI exhibit cardiovascular responses during body weight−supported exercise. Findings indicate that body weight−supported stepping provides a minimal cardiovascular challenge for individuals with paraplegia. Emphasis on low weight support during locomotor training can trigger additional heart rate adaptations.

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Locomotor training performed in conjunction with a treadmill and body weight support (BWS) system has been used as a neurologic intervention to rehabilitate walking after spinal cord injury (SCI).[1-6] As a form of exercise, completion of a regimen of stepping has been associated with higher peak oxygen consumption (V_{O_2}peak)[6] during stepping in individuals with SCI. Likewise, regular training improved left ventricular and coronary artery function[7] and decreased resting heart rate and blood presssure.[8-10] These findings suggest that locomotor training can be an effective way to enhance cardiorespiratory health after motor incomplete SCI. However, since all individuals in the noted studies were able to stand and step to some degree (ie, motor incomplete SCI), the effectiveness of this training to provide cardiorespiratory benefit across a wider spectrum of function (ie, motor complete SCI) is still unknown.

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It is not clear whether the beneficial effects of this mode of training can be elicited in individuals with no voluntary motor function (ie, motor complete SCI). Unlike a motor incomplete injury, individuals with motor complete SCI are entirely dependent on external assistance to move their legs, thus making the exercise passive in nature. Ditor et al[11] examined the effects of 4 months of locomotor training on cardiovascular fitness in participants with motor complete SCI and found improvement in vascular compliance. However, the effect on resting heart rate was highly variable, and overall, no significant changes were reported. The authors concluded that walking with BWS did not provide a significant stimulus to elicit cardiovascular adaptations in motor complete SCI.[11] This finding is consistent with data that suggest that active participation during stepping is required for optimally stimulating metabolic responses in individuals with SCI.[6,12-14]

Other findings, however, suggest that individuals with motor complete SCI can also attain cardiorespiratory benefits from BWS exercise.[15-17] Harkema et al[17] demonstrated that a training regimen emphasizing lower limb loading not only enhanced muscle activity in participants with clinically complete SCI, but also improved resting blood pressure and orthostatic response to standing. In contrast to the study by Ditor, Harkema concluded that BWS exercise improved cardiovascular function. It is known that standing and stepping with BWS can elicit muscle activity in the trunk and lower limbs in individuals with clinically complete SCI.[18-21] Moreover, activity in the leg muscles is enhanced when treadmill speed or load is increased.[19,20] Maximizing load on the legs may be essential to trigger cardiorespiratory responses in individuals with injuries classified as motor complete. However, the effect of loading during stepping on a treadmill with BWS on cardiorespiratory responses in motor complete SCI has not yet been examined.

The aim of the present study was to examine whether increasing load during stepping elevates oxygen consumption ($\dot{V}O_2$) and heart rate in individuals with motor complete SCI. The magnitude of cardiorespiratory responses to activities performed during a typical locomotor training session was assessed in individuals with SCI who had no ability to stand or step without assistance. Load was maximized by providing individuals with a relatively low level of BWS, whereas high BWS was associated with less loading. We hypothesized that decreasing BWS provided during exercise would elevate $\dot{V}O_2$ and heart rate to be within target ranges for enhancing physical fitness. Values measured in individuals with motor complete SCI were compared with the responses of able-bodied individuals performing similar tasks.

Methods

Participants with motor complete SCI (SCI, n=8) were recruited from a local rehabilitation hospital (Rancho Los Amigos Rehabilitation Hospital, Los Angeles, CA) and from a therapeutic exercise program on the campus of California State University, Los Angeles (The Mobility Center at California State University, Los Angeles).

List of abbreviations:

BWS	**body weight support**
rpm	**revolutions per minute**
SCI	**spinal cord injury**
$\dot{V}O_2$	**oxygen consumption**
Vo_2peak	**peak oxygen consumption**
$\dot{V}O_2R$	**oxygen consumption reserve**

Individuals with injury confined to the lower thoracic spine were recruited to participate in the study since persons with SCI at or below the T5 level can have an intact and competent cardiac sympathetic response to exercise.[22] Of the participants recruited for the study, 3 had an SCI that included the T5 level. Inclusion criteria were as follows: 1) 18 to 55 years of age; 2) a stable medical condition without comorbidities that could interfere with exercise (eg, uncontrolled diabetes, uncontrolled hypertension, underlying unstable cardiopulmonary disease, active liver or kidney disease); 3) no painful musculoskeletal dysfunction, unhealed fracture, contracture, pressure sore, or urinary tract infection; and 4) inability to take a step without external assistance. All participants obtained written medical clearance from their physician to perform partial weight-bearing treadmill exercises. None of the participants were able to stand and step without external assistance, as was assessed while in the BWS system. None of the participants reported that they were currently performing regular exercise. Two participants (SCI 3, SCI 5) reported that they were currently taking antispasticity medication (baclofen), which is known to diminish muscle activity levels and have the side effects of low blood pressure and respiratory depression. A convenience sample of healthy, able-bodied participants (AB, n=8) was also recruited for comparison to the SCI participants. Participant characteristics including time since injury and injury level are listed in table 1. All procedures followed protocol approved by the local institutional review board. Data used in this study were collected as part of the master's theses of 2 of the authors (E.C.J., S.M.H.).

Cardiorespiratory data collection

$\dot{V}O_2$ data were computed from expired air and expressed in milliliters per kilogram of body weight per minute ($mL \cdot kg^{-1} \cdot min^{-1}$) using the Sensormedics 2900 metabolic measurement system.[a] Heart rate data were reported in beats per minute as detected by a heart rate monitor.[b]

Task conditions

Outcome measures were collected when participants were 1) sitting quietly in a wheelchair (Seated), 2) standing with a high percentage of BWS (StandHWS), 3) standing with a low percentage of BWS (StandLWS), 4) stepping over a treadmill with a high percentage of BWS (StepHWS), and 5) stepping over a treadmill with a low percentage of BWS (StepLWS). Each condition lasted until a steady state was reached in the $\dot{V}O_2$ measurement (about 5min). The recorded value was the average of the last 3 data points of the steady-state condition (ie, when values were no longer increasing over time). Weight support was provided during standing and stepping by using a harness attached to a BWS system.[c] During high weight support conditions, BWS was provided at the highest level that allowed for therapists to move the participants' legs easily through the step cycle. Actual levels of BWS ranged from 50% to 90%. During low weight support conditions, the BWS percentage was dropped to levels that enabled gait trainers to move the participants' legs through the step cycle. Actual levels of BWS ranged between 20% and 35%. Treadmill speed was set to 2.4km/h (1.5mph).

Manual assistance of trunk and lower body kinematics during stepping was provided by a skilled team of trainers. The details of manual assistance have been described elsewhere.[1,23] Briefly, for assisting leg movements, trainers stimulated muscle tendons to facilitate contractions in leg flexor and extensor muscles during the appropriate phases of the gait cycle. The amount of assistance