

Physiologic responses to arm ergometry and leg FES ergometry in pediatric spinal cord injury

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Abstract

This study examined the differences between heart rate (HR) and oxygen consumption (VO₂/kg) during upper extremity (UE) ergometry versus lower extremity ergometry using functional electrical stimulation (LE-FES) in children with spinal cord injury (SCI). Nine children with motor complete SCI were tested using UE and LE-FES ergometry. HR was measured by electrocardiography or by pulse oximetry, and VO₂/kg was measured via breath-by-breath analysis using a metabolic cart. During each test, resistance or power output was increased every minute until fatigue occurred. A 2 x 2 ANOVA was used to compare HR and VO₂/kg between UE and LE-FES ergometry and between children with SCI above T6 and at T6 or below. There was a greater change in HR ($p < .0001$) and VO₂/kg ($p = .029$) during UE ergometry as compared to LE-FES ergometry for all children, and children with injuries at T6 or below had greater increases in HR ($p = .018$) and VO₂/kg ($p = .04$) than children with injuries above T6. These findings are consistent with reported exercise effects in adults with SCI. This information is important due to the growing concern about the cardiovascular health of adults with SCI, and focus on the potential benefits of LE-FES assisted exercise. However, these same benefits have yet to be reported for children.

1. INTRODUCTION

The cardiovascular health of adults with spinal cord injury (SCI) is of growing concern, with numerous studies focusing on the potential benefits of volitional and/or functional electrical stimulation (FES) assisted exercise. However, the same

benefits in children with SCI have not been studied. This has prompted a pilot investigation at our institution into the effects of exercise in children with SCI.

Several studies have focused on cardiovascular health in individuals with SCI. Bauman reported that individuals with SCI had an increased risk of developing a cardiovascular disease at an earlier age, and that cardiovascular disease was the leading cause of death in individuals with SCI of more than 30 years, or who were above the age of 60.¹ Cardiovascular disease is the second leading cause of death for the individual with an SCI, behind respiratory complications.² Additional studies point to a correlation between the severity of SCI and an increasing risk of cardiovascular disease.³ However, this correlation exists because individuals with higher levels of SCI have a higher incidence of modifiable risk factors, including a decreased activity level and a higher body mass index.⁴ This stresses the importance of providing exercise and modifying lifestyle at an early age.

Lower extremity FES (LE-FES) ergometry has been suggested as a way to improve cardiovascular fitness in individuals with SCI. Barstow et al.⁵ reported that heart rate (HR) and oxygen consumption (VO₂) responses were blunted when adults with SCI participated in LE-FES ergometry. Barstow et al.⁶ later studied potential differences in responses between incremental arm ergometry and LE-FES ergometry to determine if a similar blunting of responses occurred during arm ergometry. Their study showed that adults with SCI obtained a higher peak HR and VO₂ during incremental arm exercise as compared to LE-FES ergometry, suggesting that the blunting with LE-FES ergometry may be

due to decreased muscle mass and deconditioning rather than cardiac dysfunction. However, these same effects have not been studied in children with SCI.

The purpose of this study is to determine the differences between HR and VO₂/kg during UE ergometry versus LE-FES ergometry in children with SCI as part of an ongoing research study on the effects of a LE-FES ergometry training program in children with SCI. A secondary purpose is to determine differences in these variables between children whose injuries impact the autonomic nervous system (above T6) and those with intact autonomic systems (T6 and below).

2. METHODS

Nine untrained children with motor complete SCI (Table 1) were tested using UE and LE-FES ergometry. Six of these children had injuries above T6.

Table 1: Subjects

Subject Age (yrs)	Time Since Injury (yrs)	Level of Injury
11	8	C7
6	1	T7T8
11	4	T1T2
7	3.5	T3
13	7	T5
7	3	T4T5
5	4.5	T10
8	5.5	T3T4
12	8	T7

Heart rate (HR) and oxygen consumption (VO₂/kg) data were collected during UE ergometry (Rand-Scot, Inc., Fort Collins, CO) and during LE-FES ergometry (Restorative Therapies, Inc., Baltimore, MD) with a target cadence of 40 revolutions/minute (rpm). Blood pressure measurements were taken throughout each test to monitor for safety.

During both tests, VO₂/kg data were collected via breath-by-breath method using a Sensormedics Vmax29 metabolic cart. Subjects wore a small airtight facemask over

the mouth and nose that holds a flow sensor that records VO₂ as air passes through the tube. HR was measured during upper extremity ergometry using a 3 lead electrocardiography (ECG) system that synchronized the HR and VO₂ data. During LE-FES ergometry, the ECG system could not be used as the stimulation obliterated the ECG signal. Therefore, a pulse oximeter was placed on the subject's finger to measure HR, which was recorded every 10 seconds and then manually synchronized with the VO₂/kg data.

VO₂/kg and HR were measured under four consecutive conditions: 1) sitting quietly for 5 minutes to establish steady state resting values, 2) cycling for 1 minute to allow the body to warm-up, 3) cycling with increases in resistance (LE-FES) or power output (UE ergometry) every minute and 4) sitting quietly to establish 3 minutes of steady state recovery values. Criteria for stopping the exercise phase were cycling at less than 25 rpm during the LE-FES test and exhaustion for the UE ergometer test. All resistance and power output increases were the same across all subjects regardless of body weight and were the smallest increments allowed by each machine.

The change in HR and VO₂/kg was calculated for each test by subtracting the average resting value from the highest value obtained during exercise. A two-way ANOVA was used to compare the values between LE-FES and UE ergometry and the values between subjects with SCI above T6 and those with SCI at T6 and lower. Significance was determined at the 0.05 level.

3. RESULTS

VO₂/kg data were not collected on 3 subjects who had difficulty tolerating the mask during either or both tests. Therefore VO₂/kg data were analyzed based on 6 subjects only (5 with SCI above T6 and 1 with SCI at T7 or below) and was not compared between groupings based on level of injury.

There was a greater change in HR ($p < .0001$) and VO_2/kg ($p = .029$) during UE ergometry as compared to LE-FES ergometry for all children, and children with injuries at T6 or below had greater increases in HR ($p = .018$) than children with injuries above T6 regardless of the test (Figure 1). For each child regardless of injury level, there was a greater change in HR and VO_2 during UE vs. LE-FES ergometry. The length of time for the two tests did vary with the UE ergometry test lasting 3.3 ± 1.7 minutes and the LE-FES ergometry test lasting 15.1 ± 14.2 minutes.

4. DISCUSSION

These findings are consistent with reported exercise effects in adults with SCI.⁶ As the children in this study were untrained, the impact of deconditioning of the lower extremity muscles is unknown. The VO_2/kg results should be interpreted with caution when comparing subjects with injuries above T6 to those with injuries at T7 and below, as only one subject with an injury at T7 or below was included in this analysis. This information is important due to the growing concern about the cardiovascular health of individuals with SCI, with numerous studies focusing on the potential benefits of volitional and/or LE-FES

assisted exercise. However, these same benefits have yet to be reported for children with SCI. The children in this study will be retested using UE and LE-FES ergometry after participating in a one-year program of LE-FES cycling, passive cycling, or electrical stimulation exercise to determine any potential effects on cardiovascular health.

The difference in length of time between the two tests is also interesting. The children could dramatically increase HR and VO_2 during UE ergometry but could only sustain this for a short period of time. Perhaps a less dramatic increase over a longer period of time would be more beneficial. Future work is needed to examine optimal ways of using LE-FES ergometry to provide greater increases in HR and VO_2 during exercise.

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Acknowledgements

This study was funded by Shriners Hospitals for Children, Grant #8540.

