Electrical muscle stimulation can be used to elicit incremental cardiovascular exercise response and subjective effort without undue discomfort in adult subjects.

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Abstract

Previous investigations have demonstrated that EMS can be used to elicit a cardiovascular exercise response in adult subjects. However, this may not be well tolerated by all subjects. This study was carried out to establish the energy cost of a pattern of rhythmical lower extremity muscle contractions induced by low frequency electrical muscle stimulation at incremental intensities in healthy subjects and to relate energy cost to perceived exertion and comfort during stimulation. Four healthy adult subjects underwent VO2max testing using a cycle protocol to establish their maximal aerobic capacity. They then completed an incremental 1-hour session in which their quadriceps and hamstring muscle groups were rhythmically stimulated whilst their oxygen consumption was measured using open circuit spirometry and their rate of perceived exertion and comfort levels were recorded. We observed a consistent dose response relationship across all 4 subjects when energy cost was related to stimulation intensity. This was associated with corresponding changes in RPE and CP50 scores. RPE and CP-50 scores at successive stages were highly correlated with energy cost (r= 0.94 in both cases). These results suggest that rhythmical EMS induced leg muscle contractions can be used to elicit a consistent cardiovascular exercise response at therapeutic intensities without undue discomfort.

1 Introduction

Despite the importance of physical activity, sedentary lifestyle is progressively increasing in modern society. The World Health Organization projects that by 2015, approximately 2.3 billion adults will be overweight. Furthermore, increasing sedentary lifestyles are being implicated in the high incidence of cardiovascular diseases in modern society.

It is widely acknowledged that regular participation in physical activity of moderate to high intensity is required for maintenance of cardiovascular health as well as controlling body weight. However, adults frequently report that their busy schedules do not permit inclusion of repeated bouts of voluntary exercise and exercise participation levels are low. A therapeutic modality that has received a lot of attention in this area in recent years is electrical muscle stimulation mediated exercise (EMS-EX). We have previously demonstrated that low frequency EMS can be used to elicit, without loading the limbs or joint, a repeatable physiological response that is consistent with cardiovascular exercise with no adverse effects (1). Repeated exposure to EMS-EX over an extended period results in significant improvements in maximal aerobic capacity, muscle strength, and capacity for physical activity in sedentary adults (2). In more recent work (yet to be published) we have demonstrated that this form of EMS can be used to elicit clinically significant cardiovascular exercise responses in obese adults.

It is clear that this form of EMS therapy has much to offer at a clinical level in the management of conditions such as obesity and chronic heart failure. However, what is not clear to date is whether or not people would be willing to use EMS-EX in this fashion over an extended period to augment their cumulative load of physical activity. There is a widespread perception that EMS is uncomfortable, especially at the intensities that are required to produce the large scale muscle contractions that are necessary to elicit cardiovascular exercise responses. However, we have recently modified our approach to EMS-EX including an increase in electrode sizes, therefore reducing current density in an effort to improve comfort levels.

The purpose of this study is to investigate the acute physiological and subjective effect of initial exposure to this modified form of EMS-EX in adults. To achieve this aim we have recorded perceived exertion, comfort levels, and relative energy cost at incremental EMS-EX stimulation intensities in 4 healthy male subjects and have analysed the relationships between measured variables. This will provide an early insight into the relationships between exercise intensity and comfort/exertion with this form of EMS-EX and will help us to forecast its potential utility as a means of
augmenting physical activity load in patient populations, including those with mobility limitations, in the future.

2 Methods

2.1 Subjects

Four healthy adult male subjects volunteered to participate in this study. The institutional Ethics Committee approved the study and written informed consent was obtained in all cases. The 4 subjects had a mean age of 28.8 ± 8.4 years and an average mass and body mass index (BMI) of 77.3 ± 10.6 kg and 25.7 ± 2.6 kg/m² respectively. All subjects were recruited within the University, were free from illness or injury, and were physically active at the time of participation in the study.

2.2 Measurements

Maximal aerobic exercise capacity was evaluated using an incremental cycle ergometer test protocol with simultaneous cardiopulmonary gas exchange analysis. Subjects wore a facemask and a gas analysis system (Quark b², Italy) was used to measure the expired oxygen and carbon dioxide concentration and volume. $\dot{V}O_2$ was calculated from these measurements. Subjects were required to pedal at incremental workloads until any of the following endpoints were reached; a levelling of $\dot{V}O_2$ response despite increasing exercise intensity, abnormal cardiovascular signs, or fatigue. In all cases in this investigation the reason for terminating the treadmill test was subject fatigue. Peak $\dot{V}O_2$ was calculated from the average $\dot{V}O_2$ measurement during the last 30 seconds of the cycle test at each test session. Heart rate (HR) was also recorded throughout the test.

Energy cost due to stimulation was measured over the course of a 1-hour EMS-EX session carried out on a separate day. This session was the second exposure to EMS-EX for each subject as all had been offered one habituation session prior to agreeing to participate in the study proper. Subjects performed their EMS-EX session in a half-lying position and were instructed to turn the stimulation intensity up in increments of 3-5% of maximal output every 5 minutes, starting at 20% of maximal output. Physiological measurements, including $\dot{V}O_2$ and HR were recorded at rest and throughout the hour long session using open circuit spirometry as described above. Subjects were required to rate their level of comfort and perceived exertion during the final minute of each stage. Perceived exertion was assessed using the Borg Rate of Perceived Exertion (RPE) scale (3) and level of comfort was rated using the Category Partitioning (CP-50) scale (4). The CP-50 categorises discomfort into 5 separate 10 point subscales ranging from no discomfort to maximum discomfort. Scores of less than 20 indicate no or mild discomfort.

2.3 Stimulation

A specially designed hand held muscle stimulator (NT2010, BioMedical Research Ltd, Galway, Ireland) was used to produce rapid rhythmical contractions in the large lower extremity muscle groups in this investigation. The stimulator current waveform was designed to produce rhythmical contractions in the lower extremity muscle groups occurring at a frequency of 5 Hz. The maximum peak output pulse current used in the present study was 200 mA. Impulses were delivered through 4 adhesive electrodes on each leg (area per leg = 800 cm²). These were applied to the body via a neoprene ‘wrap’ garment that was secured to the thigh with Velcro straps. This array of electrodes produced contractions in the quadriceps, hamstrings, and calf muscles.

2.4 Data Analysis

The average $\dot{V}O_2$ was calculated for each 5-minute stage during the session for each subject. EMS-EX $\dot{V}O_2$ for each stage was then expressed as a percentage of $\dot{V}O_2$ max for each stage for all subjects to describe energy cost. Pearson’s correlation coefficients were calculated to investigate the relationships between group average RPE, CP-50 and energy cost.

3 Results

All tests were completed by subjects without any difficulty. Group mean $\dot{V}O_2$ max during the cycle test was 37.4 ± 3.1 ml/min/kg indicating that these subjects were of moderate fitness capacity. Individual physiological and subjective responses to each stage of the incremental EMS-EX session are detailed in Figure 2. R values for relationships between variables at each stage are outlined in Table 1.

Table 1. Pearson’s Correlation Analysis (r) for group averages at each stage

<table>
<thead>
<tr>
<th></th>
<th>RPE</th>
<th>CP-50</th>
<th>Energy Cost</th>
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<tr>
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<td></td>
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<tr>
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<tr>
<td>Energy Cost</td>
<td>0.94</td>
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Figure 1. Location of Stimulating Electrodes
4 Discussion

These results suggest that EMS-EX can be used to elicit a therapeutic cardiovascular exercise effect without causing discomfort in adult subjects. We observed a very strong relationship between average RPE, CP-50 and energy cost as stimulation intensity increased in these 4 subjects. The subjects in this study reached exercise intensities of between 30 and 60% of their VO₂ max prior to entering a zone where their level of discomfort could be described as ‘moderate’. It is interesting to note that the subject at the lower end of this scale exhibited high RPE and CP-50 scores throughout the incremental test, even at stages where they were below 15% of their VO₂ max. This could suggest a person who does not tolerate EMS in general or has an unusual perception of their level of exertion.

To date a limiting factor of EMS has been that the threshold of effective stimulation often exceeded the comfort levels of the subject. In reality many patients would use EMS at intensities that give only marginal benefits. Not that the therapies don't work but rather that greater intensities are required for optimal gains than users would routinely tolerate. In this set-up, effective aerobic exercise using EMS seems to be well within the comfort zone of the subjects. Hence, subjects are likely to routinely use it, unsupervised, at therapeutically beneficial rates. This opens the possibility of using this type of EMS in many patient populations.

5 Conclusion

This investigation demonstrates that there is significant potential for EMS-EX to provide an alternative means of comfortable and effective cardiovascular exercise therapy in the general and in patient populations.

6 Literature


Figure 2. RPE, CP-50 and Energy Cost during each stage of the incremental EMS-EX session.