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THE USE OF ELECTRICAL MUSCLE STIMULATION TO ELICIT A CARDIOVASCULAR EXERCISE RESPONSE WITHOUT JOINT LOADING: A CASE STUDY.

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ABSTRACT

THE USE OF ELECTRICAL MUSCLE STIMULATION TO ELICIT A CARDIOVASCULAR EXERCISE RESPONSE WITHOUT JOINT LOADING: A CASE STUDY. **Brian Caulfield, Louis Crowe, Conor Minogue, Prithwish Banerjee, Andrew Clark**. **JEP**online 2004;7(3):84-88. To date, electrical muscle stimulation (EMS) has not been used to elicit a cardiovascular exercise effect in healthy adults without joint loading. This case study was carried out to address this issue. We have developed an EMS system capable of eliciting a cardiovascular exercise response with minimal gross movement or loading of the limbs or joints. It is modelled on shivering, the natural process for generating heat when body temperature falls. One untrained male subject (age 31 yr; weight 70 kg) completed 4 treatment sessions using this system during which the stimulus intensity was increased in increments of 10% every 3 min to reach maximum output at each session. The same subject also underwent one single EMS session of 4 hours duration at a stimulation intensity of 40-60% of maximum output. VO_2 and HR responses observed during the first 4 sessions were within the zone required for cardiovascular training. At peak stimulation intensity, the subject's workload was 12 METs. VO_2 ranged from 20-25 ml/kg/min during the 4-hour session. The subject expended a cumulative total of 1865 Kcal during this session. This data suggests that the benefits of vigorous exercise may now be achieved through the use of electrical stimulation. There are many potential applications for this technology.

Key Words: Electrical Stimulation, Exercise therapy, Oxygen consumption.

INTRODUCTION

The benefits of electrical muscle stimulation (EMS) in medicine and sport are well established from a wide body of research. The use EMS to elicit contraction of skeletal muscle has been effectively employed for a wide variety of applications including prevention of muscle atrophy (1), muscle strengthening (2), and management of incontinence (3), spinal deformities (4) and spasticity (5). Functional electrical stimulation (FES) of muscle has been used with some degree of success in the spinal cord injured population to facilitate locomotion (6).

In recent years investigators have directed attention to the use of EMS technology to elicit a cardiovascular response. This has primarily involved the use of EMS to induce leg cycling exercise (EMS-LCE), and therefore dissipate energy through a cycle ergometer, in spinal cord injured patients. EMS-LCE can result in VO_2 levels of the order of 0.6-0.8 L/min in SCI subjects (7,8). Training with EMS-LCE can also result in improvements of 10-35% in aerobic capacity in SCI subjects (9,10). Conventional EMS-induced tetanic muscle contractions have a minimal effect on energy consumption. Eijsbouts and co-workers demonstrated that bilateral stimulation of quadriceps, hamstrings, gastrocnemius and tibialis anterior muscle groups at maximally tolerated intensity could produce an increase in oxygen consumption (VO_2) of approximately 0.1 L/min in healthy adults at rest and during arm cranking exercise (11). Such levels of VO_2, in isolation, are unlikely to result in therapeutic benefit.

To date, EMS technology has not been used successfully to elicit a vigorous cardiovascular exercise response without loading the limbs or joints. Such an application would provide many benefits for sport and medicine. Unloaded EMS induced cardiovascular exercise could provide an attractive alternative to customary forms of cardiovascular exercise that involve repetitive joint loading (such as running). It could also be used to induce a cardiovascular exercise response in people who experience barriers to participation in voluntary weight-bearing exercise, for example those with degenerative joint disease, obesity or spinal cord injury (12).

We have developed a novel EMS system capable of eliciting a cardiovascular exercise response with minimal gross movement or loading of limbs or joints. The pattern of EMS used in this investigation was modelled on shivering, which is the natural process for generating heat when body temperature falls. Shivering generates heat with no external work through rhythmical muscle contractions, occurring at a rate of approximately 4-8 Hz (13). We attempted to mimic this pattern of muscle activity by using EMS to elicit cardiovascular exercise via rapid, short duration, rhythmical contractions in the large lower extremity muscle groups. The purpose of this case study was to show that this form of EMS is capable of eliciting a vigorous cardiovascular exercise response in a healthy adult male.

METHODS

One male subject (age 31; weight 70kg), who gave written informed consent prior to participation, completed 4 EMS sessions using a portable muscle stimulator over a two-week period. Sessions were performed at the same time each day with the same electrode positioning and food intake. The output stimulus intensity of the stimulator was increased by intervals of 10% every three minutes to reach maximum output during each 30-minute session. The same subject also underwent one single EMS session of 4 hours duration whilst watching television in a seated position. The stimulation intensity was varied between 40 and 60% of maximum output over the course of this session. The subject's physiological response to stimulation was monitored and recorded throughout each session using a Quark B2 (Cosmed, Italy) open circuit spirometry system.

A specially designed hand held muscle stimulator (BioMedical Research Ltd, Galway, Ireland) powered by a 9 V battery was used in this investigation. The stimulator current waveform was designed to produce rhythmical contractions in the lower extremity muscle groups occurring at a frequency of 4 Hz. The maximum peak output pulse current used in the present study was 300 mA. Impulses were delivered through 5 silicon rubber electrodes on each leg (area per leg = 600 cm^2) as illustrated in Figure 1. These were applied to the body via a pair of tight fitting shorts, which extended to the knee. The quadriceps, hamstrings

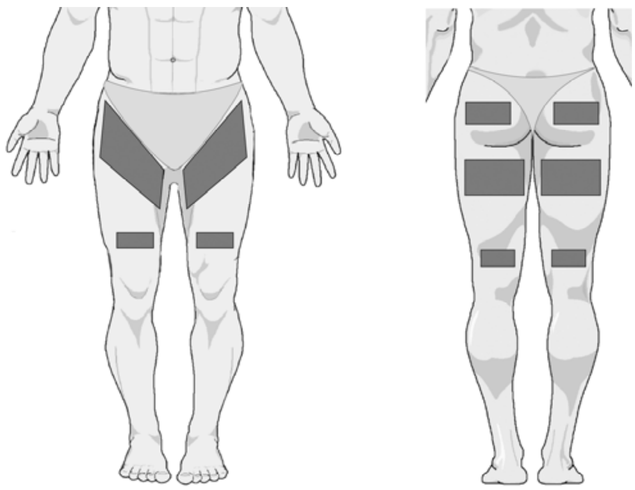

Figure 1. Location of stimulating electrodes.

and gluteal muscles were stimulated while the subjects lay supine for all stimulation sessions.

RESULTS

The subject completed all stimulation sessions without difficulty. The toleration of the stimulus, both in time and intensity, was principally limited by subject fatigue. Tachypnoea, tachycardia, sweating, and fatigue were all present at higher stimulation intensities. Average oxygen consumption (VO_2) (ml/kg/min) and heart rate (beats/min) at each stimulation level during each of the four 30-min sessions are illustrated in Figure 2. These results demonstrate that a repeatable linear dose response relationship exists between stimulus intensity and physiological responses. In addition physiological responses were consistent with responses that would be expected in voluntary exercise such as cycling or running. VO_2 levels of the order of 5 and 10 METs were consistently apparent at 40 % and 80 % of maximum stimulus intensity respectively. This was associated with corresponding mean heart rate responses of 93 and 163 beats/min.

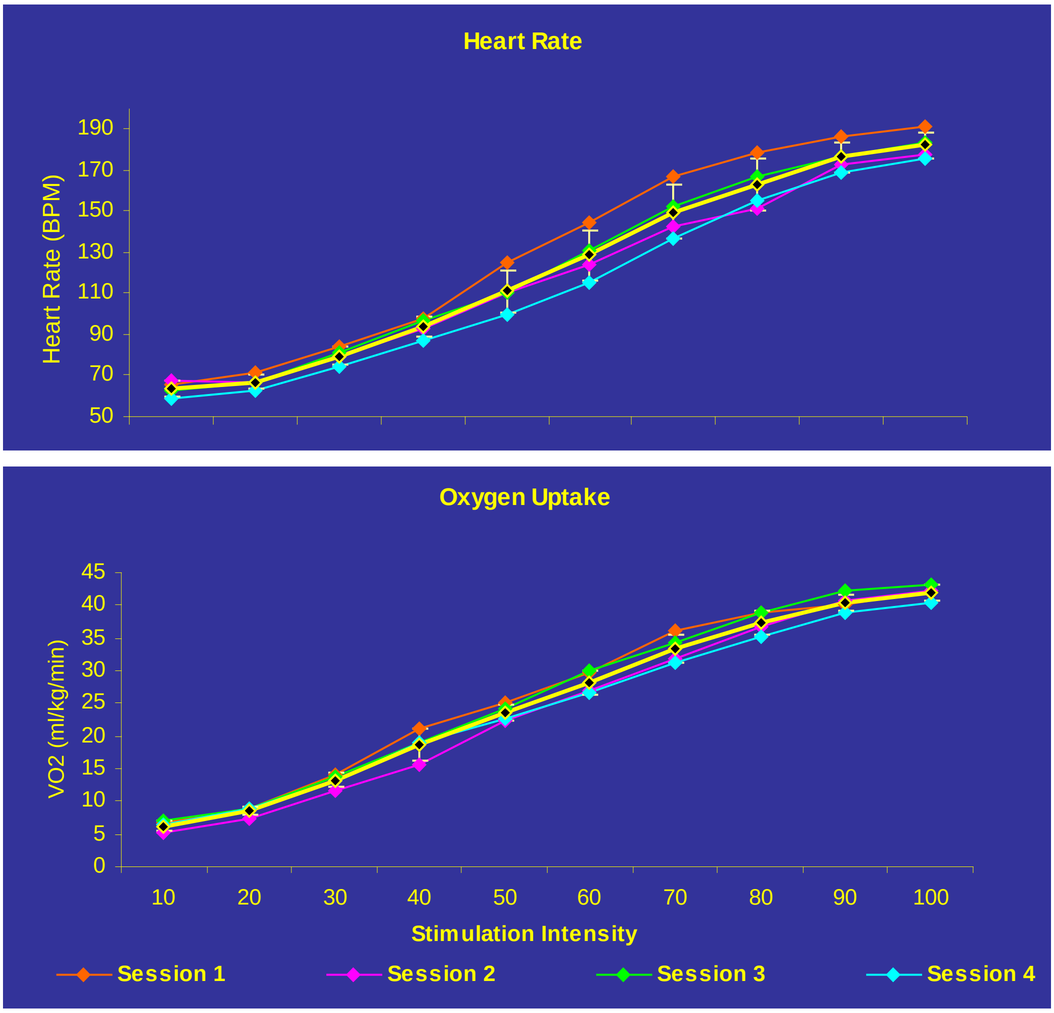

Figure 2. Physiological responses to repeated electrical muscle stimulation over 4 sessions.

VO_2 (ml/kg/min) and cumulative energy expenditure (Kcal) during the 4-hour session are illustrated in Figure 3. Breaks in the VO_2 graph correspond to breaks in recording due to drinking water and changing batteries in the stimulator. The subject expended a cumulative total of 1865 Kcal during the 4-hour session. This level of energy expenditure is equivalent to this subject running 15 miles at a 9 min/mile pace (13).

DISCUSSION

This data suggests that the benefits of vigorous exercise may now be achieved through the use of electrical stimulation. We have demonstrated that EMS can be used to elicit a physiological response consistent with that expected with high intensity cardiovascular exercise. In addition, he also exhibited very high cumulative energy expenditure during one prolonged session. Our subject experienced no adverse effects from the stimulation and reported that his principal limiting factor was fatigue.

It is not clear whether stimulation at high intensities would prove acceptable to all as there is a great deal of individual variability in terms of reported comfort levels with EMS (14). However, we have previously observed good tolerance for sub-maximal stimulation (40% of maximal output) using this form of EMS in a group of 10 healthy adults (15). This sub-maximal stimulation was associated with an average exercise workload of approximately 4 METs.

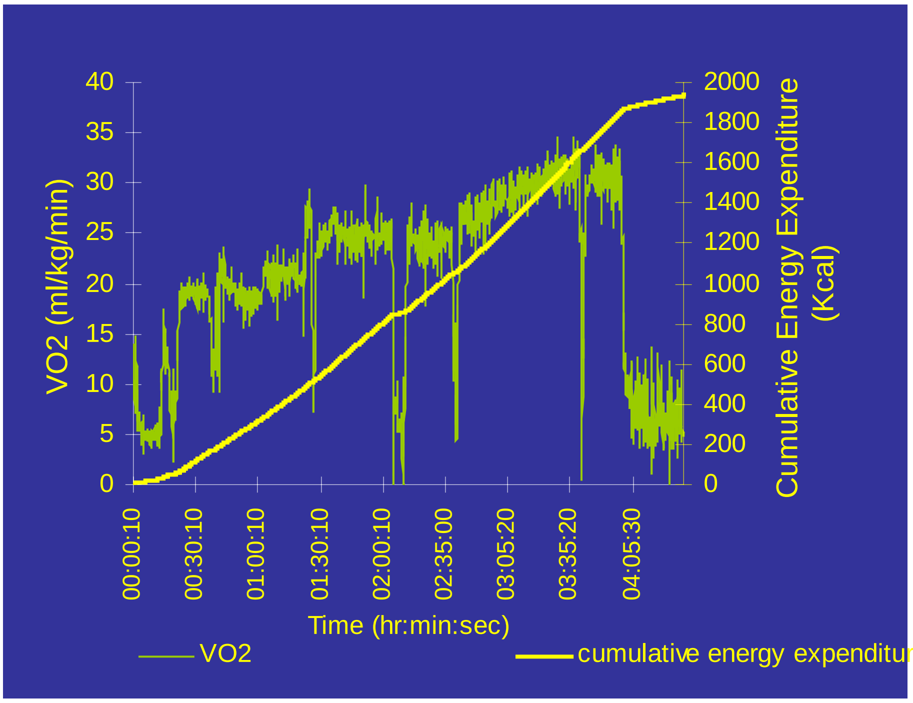

Figure 3. Physiological response to prolonged electrical muscle stimulation.

There are many potential applications for this form of EMS. Some of the more obvious applications are in those who possess barriers to participation in more 'traditional' forms of voluntary exercise such as walking, running or cycling. This would include spinal cord injured patients, people suffering from obesity or those with degenerative joint disease. It could also as an attractive alternative for those in sport who have a high requirement for cardiovascular exercise training yet wish to minimize the amount of repetitive joint loading they place upon their body. Further work needs to be done to investigate the mechanism of action of this form of EMS and to quantify its effects in different populations.

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