High-Intensity Virtual-reality Arm plus FES-leg Interval Training in Individuals with Spinal Cord Injury

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Abstract: This study investigated the effect of high-intensity arm and FES-leg cycle training in a virtual reality environment on power output, aerobic fitness and blood biochemistry in persons with spinal cord injury (SCI). Eight individuals with chronic SCI undertook 6 weeks of high-intensity (80-90% HRpeak) interval training using an arm+FES-leg tricycle. As a result of the virtual reality interval training program, subjects increased their peak aerobic fitness by 20% (p<0.05). Their body mass-adjusted VO2 peak also significantly increased from 19.3±3.4 mL·kg⁻¹·min⁻¹ to from 23.2±3.4 mL·kg⁻¹·min⁻¹. Arm+ leg peak power output during “hybrid” exercise was raised from 52.5±10.4 W to 70±12.0 W (P<0.05). Total cholesterol, HDL, LDL and oral glucose tolerance results were unchanged after training.

Keywords: arm+leg exercise, virtual reality, hybrid exercise

Introduction

Upper body exercise (e.g. wheelchair propulsion, arm cranking) is often recommended for people with spinal cord injury (SCI) to maintain or enhance their aerobic fitness and upper-body muscular endurance, but due to the relatively small muscle mass in their arms such exercise may not be as beneficial as leg exercise. However, FES-evoked leg exercise (e.g. cycling, stepping) is by itself not sufficient stimulus to promote cardiorespiratory fitness if the leg muscles are atrophic and de-trained [1].

Recently, Hasnan and colleagues [2] have demonstrated that combined voluntary arm and FES-evoked leg exercise (“hybrid”) elicited a higher oxygen uptake and greater cardiovascular demand compared to arm exercise or FES cycling alone. Commercially-available hybrid exercise devices have enabled outdoor arm+leg cycling as well as indoor virtual reality (VR) hybrid exercise for people with SCI. VR-enhanced exercise (Fig. 1) allows the participant to interact within a virtual environment mimicking outdoor overground cycling, and may provide a sense of participation and exercise motivation. Hasnan and co-workers [3] demonstrated that mean oxygen uptake and energy expenditure of indoor virtual reality hybrid exercise were no different from outdoor overground arm+leg exercise, even though “steering” and “gearing” differences contributed to different limb movements over 30-min of exercise.

The purpose of this study was to investigate the effect of high-intensity “hybrid” (arm and FES-leg cycling) interval training in a virtual reality environment on aerobic fitness, power output, lipid profiles and glucose tolerance in persons with SCI.

Methods

Eight individuals with chronic SCI undertook 6 weeks of hybrid high-intensity interval training (HIT) using an arm+FES-leg tricycle. Training sessions were either 32 min, three times per week or 48 min, two times per week. For the thrice-weekly programme, the subjects were instructed to perform four 8-min exercise intervals of high intensity training (80-90% of predicted HRmax) interspersed with four 8-min intervals of low intensity training (LIT; FES-stimulated legs only at 40% of predicted HRmax). For the twice-weekly programme, the subjects were instructed to undertake six 8-min intervals of HIT interspersed with six intervals of LIT. For both training regimes, all subjects completed 96 min of HIT and 96 min of LIT per week.

Fig 1: ‘Hybrid’ Virtual Reality Indoor Exercise

The recumbent tricycle (BerkelBike®) was positioned on Tacx i-Magic VR Trainer®, indoors in front of a flat panel monitor displaying simulated outdoor overground cycling. All training incorporated VR technology whereby the subjects trained to a pre-selected VR programme. Voluntary arm cranking was at a cadence selected by the subjects to achieve their desired exercise intensity. Computer-controlled electrical stimulation was applied bilaterally to the quadriceps, hamstrings and...
glutei to evoke leg cycling. The subjects were encouraged to cycle to their best effort within safety limits and increase/ramp up their leg stimulation intensities based on their comfort and tolerance level to a maximum stimulation intensity of 150 mA at 35Hz.

The participants were assessed for their peak cardiorespiratory responses and power output before and following completion of the six-week training programme. Heart rate and cardiorespiratory parameters were measured continuously breath-by-breath by open-circuit spirometry with a metabolic gas analysis system at rest and during the maximal effort assessments. Lipid profiles, cholesterol and oral glucose tolerance were also measured before and after the training.

Analysis of variance was utilised to investigate pre-training versus post-training differences of all variables, whereby the level of statistical significance was set to the 95% confidence limit (p<0.05). Data are presented as mean ± standard deviation. Statistical analyses were performed using the SPSS 21 statistical package.

Results

As a result of the hybrid HIT program, the subjects increased their arm-leg peak power output from 52.5±10.4 W to 70±12.0 W (P<0.05). Their peak aerobic fitness was increased by 20% (Fig. 2; p<0.05). Their body mass-adjusted VO\(_2\)peak also increased from 19.3±3.4 mL·kg\(^{-1}\)·min\(^{-1}\) to 23.2±3.4 mL·kg\(^{-1}\)·min\(^{-1}\) (p<0.05). No other resting or peak exercise cardiorespiratory variables were changed as a result of hybrid HIT training. Leg girths and volumes were also unchanged after hybrid HIT. Blood biochemistry markers of cardiovascular risk, including total cholesterol, HDL, LDL and oral glucose tolerance results were unchanged after training, although modest improvements were observed in some subjects.

FES cycling has been clinically recommended to individuals with SCI for its ability to recruit the large musculature of the legs. Yet, Vreellen and co-workers [1] and Hasnan et al [2] have shown that the metabolic responses during an acute bout of leg cycling exercise alone may not be sufficient to promote cardiorespiratory fitness in this population.

Numerous authors have recommended “hybrid” (e.g. arm-leg) exercise during rehabilitation as potentially more dose-potent to induce physiological adaptations within the cardiorespiratory system after SCI. Our 20% increase of aerobic fitness and 33% higher peak power output was more than twice that observed by Heesterbeek and colleagues [4] for a similar BerkelBike® training program. The larger increases of the current study were likely due to a longer training period and our use of high-intensity interval training (HIT) for this relatively de-conditioned population.

There are no previous studies that have investigated changes of lipid profile and oral glucose tolerance following “hybrid” exercise training in SCI. The lack of changes in these biochemical measures suggests that six weeks of twice- or thrice-weekly training, even at a high intensity, may be too short to modify these biochemical markers of cardiovascular risk in the SCI population.

Discussion

This study investigated indoor virtual-reality “hybrid” exercise training in individuals with SCI. Traditionally, augmentation of leg stimulation intensity, may be too short to modify these biochemical markers of cardiovascular risk in the SCI population.

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