# FES-evoked Leg Exercise: Is this the Best Way to Promote Aerobic Fitness and Cardiovascular Health for SCI?

Davis GM

Rehabilitation Research Centre, Exercise, Health and Performance Research Group, Faculty of Health Sciences, The University of Sydney, Sydney, Australia

## Abstract

*This paper will examine whether FES-evoked cycling and similar exercises are the best way to promote gains in aerobic fitness and cardiovascular health for spinal cord-injured individuals. Key studies from the scientific literature were contrasted, supporting or rebutting the popular view that such exercise is primarily aerobic metabolism, and hence FES-exercise or physical training will lead to gains of peak aerobic fitness. The evidence for and against the "exercise hypothesis" that physical training via FES will reduce cardiovascular risk and lower disease burden in the SCI population was also be examined. A careful analysis of these key keynote studies from the literature suggests that FES-cycling and analogous exercises does not always improve aerobic fitness nor lead to gains in cardiovascular health in wheelchair users with spinal cord injury.*

***Keywords:*** *FES exercise, aerobic fitness, cardiovascular risk, health outcomes.*

## Introduction

A healthy, able-bodied individual's peak aerobic fitness during exercise reflects an interaction of central cardiovascular responses (oxygen supply) and peripheral muscle metabolism (oxygen demand). Any potential improvement of aerobic fitness following FES-evoked exercise such as cycling, stepping or similar leg movements reflects adaptations transpiring within both the peripheral musculature and cardiovascular system. Yet, the neurohumoral responses of spinal cord-injured (SCI) individuals during leg exercise are quite different from the able-bodied population due to their atrophied leg muscle mass, post-SCI alterations of muscle morphology or histochemistry and the intrinsic differences of FES-evoked muscle contractions compared to voluntary muscle activation.

It is a popular view promoted by some clinicians and equipment manufacturers alike, that FES-evoked leg exercise always enhances aerobic fitness after SCI. Indeed, amongst some of the earliest citations of FES-cycle training with SCI individuals, both Polack and colleagues [1] and Hooker et al. [2] showed significant increases of peak oxygen consumption ($VO_2$) after 4-6 months of training. Yet these studies, and those that followed, often reported quite modest improvements of peak leg metabolism after training – only ~10%, and at relatively low levels of leg $VO_2$ (less than 1.5 $l \bullet min^{-1}$). In our previous systematic reviews [3, 4], we concluded that "*the empirical evidence lends support to positive metabolic responses and increased aerobic fitness for people with SCI who participate in FES-induced exercise training programs*". However, this conclusion was stated in terms of improved leg-elicited aerobic metabolism, not peak fitness that could be achieved through arm exercise or whole-body exertion. The distinction is quite important, because it raises the question whether FES leg-exercise training by itself can improve 'central' cardiovascular responses to a degree that may reduce cardiovascular risk.

The purpose of this paper was to re-examine selected prior studies to determine whether they demonstrated significant changes of aerobic fitness that would be deemed beneficial for the cardiovascular health of individuals with SCI. As a benchmark of exercise for cardiovascular health, the current ACSM and AHA exercise guidelines for managing CVD risk factors were adopted.

## Material and Methods

Selected studies were evaluated to determine whether FES-leg exercise (i.e. cycling, upright stepping, repetitive isolated muscle contractions, etc) might meet the ACSM/AHA exercise guidelines for managing cardiovascular disease risk factors in individuals with SCI. These guidelines propose 30-min of moderate intensity (about 70-80% of maximal heart rate or peak $VO_2$) or 20-min of high intensity (> 80% of maximal heart rate or peak $VO_2$) exercise on at least five days a week.

## Results

*Some studies <u>support</u> FES leg exercise as meeting ACSM/AHA guidelines for cardiovascular health:*

Hooker and colleagues (1995) undertook a 19-week FES leg cycle training program in individuals with C5-L1 (AIS A) spinal cord injuries. The authors reported a 10% increase of leg aerobic fitness, but importantly the peak exercise intensity of FES-evoked leg exercise ranged from 94-112% of voluntary arm cranking $VO_2$peak. When steady-state FES-leg exercise was undertaken lasting 30-min (the usual duration of an exercise session) oxygen uptake was 71% of arm exercise peak fitness.

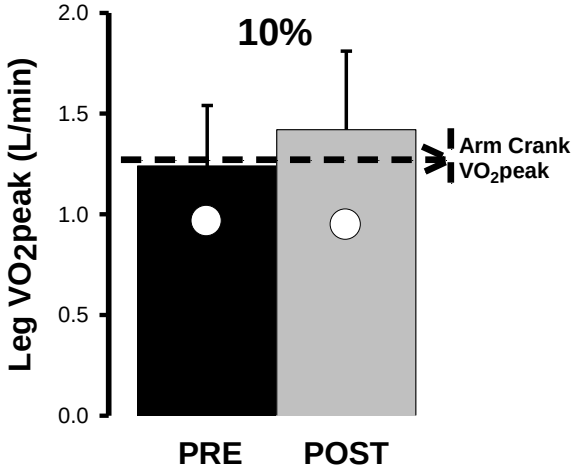


Figure 1. FES leg exercise can meet ACSM/AHA exercise guidelines. Before and after training peak leg aerobic fitness (bars) met or exceeded peak arm $VO_2$ (dashed line). Submaximal leg exercise $VO_2$ over 30-min shown as open circles (Hooker et al, [2])

These early studies have been repeated in later investigations, whereby FES leg exercise by itself or in combination with voluntary arm exercise increased aerobic fitness (reported in [3, 4]).

*Some studies advocate FES leg exercise <u>does not meet</u> ACSM/AHA guidelines for cardiovascular health:*

In contrast, numerous studies have demonstrated that;

(i) FES-evoked leg exercise by itself does not increase an individual's aerobic fitness, or

(ii) FES-leg exercise in combination with voluntary arm exercise adds little "fitness-promoting" benefit more than arm exercise alone.

Krauss et al [5] conducted a 12-week training study, wherein the first six weeks legs-only were trained via FES muscle contractions, and for the next 6 weeks arm+leg 'hybrid' training was conducted. Although both arm and leg peak aerobic fitness were significantly increased, FES-evoked leg $VO_2$peak never exceeded 45-69% of arm aerobic fitness. These data suggested that many months might be needed for leg-only exercise to make a significant contribution to whole-body aerobic fitness training.

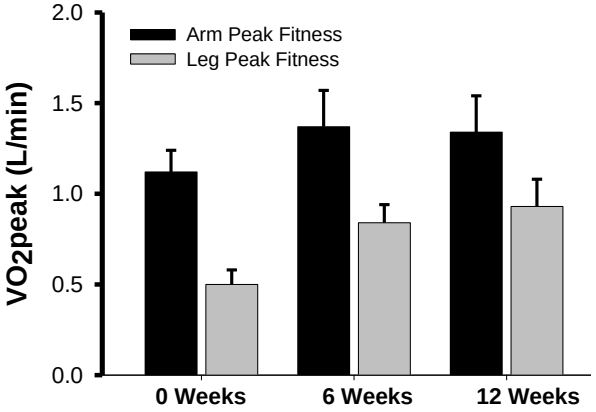


Figure 2. FES leg exercise may not meet ACSM/AHA exercise guidelines. Before, 6 weeks and 12 weeks after training, peak leg aerobic fitness (grey bars) did not met peak arm $VO_2$ (black bars) (Kraus et al, [5])

A recent study was conducted by Hasnan and colleagues [6] whereby acute exercise was performed at 40%-100% of arm-only peak, leg-only peak and arm+leg peak exercise [6]. The authors demonstrated that arm exercise and arm+leg exercise could demonstrate 'fair' aerobic training potential between 80%-100% of peak effort, but FES-leg exercise could not.

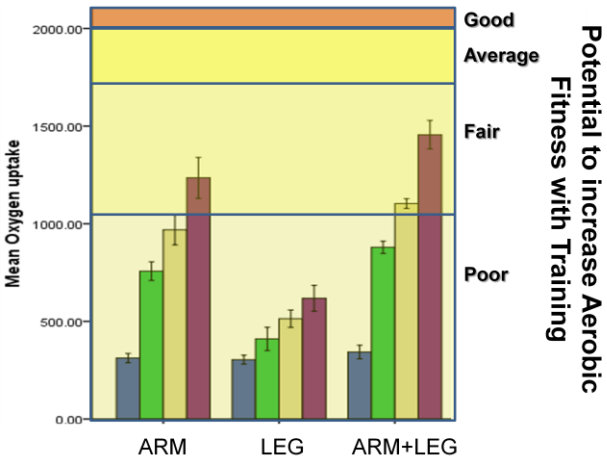


Figure 2. Potential for arm, FES-leg and arm=leg exercise to meet ACSM/AHA exercise guidelines. (Hasnan et al, [6])

## Discussion

It is a popular view that FES-evoked exercise for people with SCI increases their aerobic fitness to a degree that may provide generalised health benefits to reduce the risk of cardiovascular disease.

### *Three problems of inference:*

Yet, it is proposed that the understanding of previous (usually positive) findings have been misinterpreted due to "*three problems of inference*". These are:

1. Inferring that exercise promotes aerobic fitness based on adaptive changes to muscle morphology, histochemistry or leg metabolism
2. Inferring that an acute (single bout) elevated oxygen uptake might lead to chronically improved whole-body aerobic fitness
3. Inferring from arm and leg 'hybrid' exercise, that leg exercise alone improves aerobic fitness

### *Aerobic fitness and cardiovascular health are not the same entity*

It must also be recognised that aerobic fitness and cardiovascular health are not the same outcomes. Clilibeck and co-workers [7] noted that FES-cycling may protects against "lifestyle diseases" such as adult-onset diabetes in this population. After 8 weeks of FES cycle training they observed improved glucose response during an oral glucose tolerance test in addition to increased insulin sensitivity. Other authors have noted that FES exercise may assist in body fat management in previously sedentary wheelchair users. These benefits to cardiovascular health mat not align with peak aerobic fitness, because one outcome is about improved metabolism and the other is about elevated exercise intensity.

### *The issue of FES exercise heart rate*

Can aerobic fitness be improved without an increase of heart rate during FES exercise?

Inconsistent responses of exercise HR have been reported amongst studies. Some investigations have reported a normal exercise-induced tachycardia, whereas others have observed no change of HR during FES muscle contractions. Although the studies that we reviewed [3, 4] have shown that oxygen uptake may be elevated during FES exercise (but there is not consistency in this finding), few of them report a 'normal' cardioacceleration with such exercise.

## Conclusions

This paper sought to highlight some inconsistencies of interpretation about the purported benefits of FES leg exercise for aerobic fitness and cardiovascular health. At the current time, there are insufficient high-quality studies to position the question whether FES-evoked cycling, stepping or other modes of leg exercise provide both aerobic fitness and cardiovascular health benefits for the SCI population.

## References


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### Author's Address


Glen M Davis

Rehabilitation Research Centre
Exercise, Health, and Performance Research Group
Faculty of Health Sciences
The University of Sydney

glen.davis@sydney.edu.au