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## Gains in aerobic capacity with whole-body functional electrical stimulation row training and generalization to arms-only exercise after spinal cord injury

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### Abstract

**Study Design:** Longitudinal study in adults (n=27; 19–40 years old) with tetraplegic or paraplegic spinal cord injury (SCI).

**Objectives:** Determine physiological adaptations and generalizable fitness effects of six months of whole-body exercise training using volitional arm and functional electrical stimulation (FES) leg rowing.

**Setting:** Outpatient hospital-based exercise facility and laboratory

**Methods:** Participants enrolled in hybrid FES row training (FESRT) and performed peak exercise tests with arms-only (AO; baseline and 6-Mo) and FES rowing (baseline, 3-Mo, 6-Mo).

**Results:** Participants demonstrated increased aerobic capacity ( $VO_{2peak}$ ) after FESRT ( $p < 0.001$ ,  $n_p^2 = 0.56$ ) that tended to be higher when assessed with FES than AO rowing tests ( $0.15 \pm 0.20$  vs.  $0.04 \pm 0.22$  L/min;  $p = 0.10$ ). Changes in FES and AO  $VO_{2peak}$  were significantly correlated ( $r = 0.55$ ;  $p < 0.01$ ), and 11 individuals demonstrated improvements ( $> 6\%$ ) on both test formats. Younger age was the only difference between those who showed generalization of training effects and those who did not (mean age  $26.6 \pm 5.6$  vs.  $32.0 \pm 5.7$  years;  $p < 0.05$ ) but changes in FES

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#### Authors' Contributions

HWM was responsible for study conceptualization, data analysis and interpretation, and writing and revising the manuscript. GP was responsible for data acquisition and conducting exercise tests, and he supervised FESRT. JAT was responsible for study conceptualization, data interpretation, and revising the manuscript. IV was responsible for study conceptualization, data analysis and interpretation, and writing and revising the manuscript.

#### Data Archiving

Part of the dataset generated during and analyzed in this study is not publicly available because it is still being analyzed, but the data can be made available from the senior author on reasonable request.

#### Statement of Ethics

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

#### Conflicts of Interest

On behalf of all contributing authors, we have no conflict of interests to report.

$VO_{2peak}$  correlated to time since injury in individuals <2 years post-SCI ( $r=-0.51$ ,  $p<0.01$ ,  $n=24$ ). Lastly,  $VO_{2peak}$  improvements were greater during the first three months vs. months 4–6 (+7.0% vs. +3.9%;  $p<0.01$ ) which suggests early training adaptations during FESRT.

**Conclusions:** Gains in aerobic capacity after whole-body FESRT are better reflected during FES row testing format. They relate to high-intensity exercise and appear early during training, but they may not generalize to equivalent increases in AO exercise in all individuals with SCI.

## Introduction

Individuals with spinal cord injury (SCI) encounter an increased risk for cardiovascular disease and secondary health complications that is driven by physiological restrictions.(1, 2) Indeed, individuals with SCI have significantly lower aerobic capacity than able bodied adults (3–5) since paralyzed muscles in SCI are unable to contribute to exercise and therefore to oxygen consumption. This limits muscle and cardiovascular engagement with daily activities which are not vigorous enough stimuli to maintain fitness and decrease risk for cardiovascular disease.(6) The beneficial and protective cardiovascular health effects of aerobic exercise require training at sufficient intensity and volume.(7) (8) (9) In fact, moderate to vigorous intensity training that engages muscle mass beyond what is typically used is necessary to increase peak aerobic capacity ( $VO_{2peak}$ )(10, 11) and decrease cardiovascular risk in those with SCI.(12)

One manner for those with SCI to exercise at high intensities is by incorporating paralyzed muscle. Hybrid functional electrical stimulation (FES) exercise activates both voluntary upper body and electrically-stimulated lower body musculature, and is a previously reported technique to overcome the physiological limitation of arms-only or FES legs-only exercise. (13–15) Hybrid FES exercise results in training adaptations that surpass those of arm crank exercise or FES-exercise alone.(15–18) For example, a review of SCI exercise training studies found that higher gains in  $VO_{2peak}$  resulted from hybrid FES row training (FESRT) when compared with hybrid FES cycling and simultaneous arm crank or FES cycling alone. (2) Furthermore, previous study showed that FESRT led to greater peak aerobic capacity compared with arms-only (AO) rowing.(15) Moreover, FESRT can circumvent physiological limitations of paralyzed muscle that otherwise restrict aerobic exercise, and allows increases in aerobic capacity among adults with neurological level of injury as high as C4.(19) For wheelchair users with SCI, whole body hybrid FESRT could avoid excess musculature strain of upper body-only exercise(20) and allow longer and more intense training sessions by incorporating lower body musculature.(2) However, it is not known whether improvements in aerobic capacity during FESRT generalize to greater aerobic capacity in upper body exercise performance. Increases in  $VO_{2peak}$  that result from exercise training are due to adaptations either centrally (i.e., increased maximal cardiac output) or peripherally (increased  $a-VO_2$  difference due to changes in trained skeletal muscle). Hence, an increase in aerobic capacity with one form of exercise may translate to increases with other forms of aerobic exercise. A generalization of improved aerobic capacity to upper body exercise could decrease fatigue and physical strain during daily activities,(21) increase community mobility,(22) and hence have a great impact on independence for individuals with SCI.

Based on the training principles of specificity and overload, cardiorespiratory training adaptations are specific to those muscles or system exercised and occur when training is more intense than activities an individual did prior to training.(23–25) Given that the FESRT exercise stimulus involves volitional arm movements and facilitates high cardiorespiratory demands by incorporating electrically-stimulated lower body movements, we investigated whether training the legs in non-ambulatory individuals translated to increased AO exercise capacity. Hence, our study objective was to determine whether cardiorespiratory changes after FESRT would generalize to changes in fitness for AO exercise, by discriminating the contribution of the legs to changes in cardiorespiratory fitness. In the case of SCI and FESRT, if the adaptations were primarily peripheral, there may be no within-person increases in AO  $VO_{2peak}$  tests (i.e., the stimulated legs account for the increase in aerobic capacity with FESRT). If adaptations were central, an increase in AO  $VO_{2peak}$  might be observed due to greater maximal cardiac output (which is due to greater maximal stroke volume). This pre-post time series study examined changes in peak aerobic capacity ( $VO_{2peak}$ ) using two distinct testing methods: AO and FES tests on the rowing ergometer in the same individuals.(15) Between the tests, all participants performed six months of FESRT.

## Methods

### Participants:

Inclusion criteria for eligible participants were age 18–40 years, and a time since SCI (TSI) of at least 3 months, and performed six months of FESRT. All participants had at least partially preserved arm function to row and had quadriceps and hamstring contractile responses to electrical stimulation. Participants gave their informed consent. This study was based at an outpatient hospital exercise facility and laboratory and part of the clinical trial #NCT02139436. This trial was amended to include individuals who were more chronically injured than in the original submission, and this study only analyzes data from those who performed FESRT. The original study and amendment were approved by the Spaulding Rehabilitation Network Institutional Review Board.

### Rowing Ergometer Set-up:

As previously described, Model D Indoor Rowers (Concept2 Inc., Morrisville, VT) were adapted for people with SCI (Paddlesport Training Systems/Vermont Waterways, Inc., Hardwick, VT).(15) In AO row testing, the rowing seat was locked into place to isolate pull chain displacement for upper-body movements. For FES row testing, electrodes were placed over the motor points of the quadriceps and hamstring muscles and attached to the electrical stimulator (Odstock 4 Channel Stimulator Kit, Odstock Medical Limited Inc, Salisbury, United Kingdom). To produce rowing strokes, participants synchronized electrical stimulation timing through a button on the rower handle. FESRT stimulator parameters were 300ms pulse width and 40 Hz frequency without ramp, and stimulation intensity was increased to a maximum of 110mA.

**Measurement:**

Despite distinct set-up, the same measurement procedures were used during AO and FES rowing  $VO_{2peak}$  tests. All participants were evaluated with AO and FES tests in a random order at baseline and after six months of FESRT within one week of each other. For FES rowing  $VO_{2peak}$  tests were also completed after three months of training. Baseline testing was conducted once participants could complete continuous FES rowing for 10 minutes. Individuals refrained from consuming food for two hours prior and caffeine and alcohol for 24 hours prior to testing, and from engaging in vigorous physical activity for 48 hours prior. Peak aerobic capacity was determined from on-line computer-assisted open circuit spirometry (TrueOne 2400, Parvo Medics Inc, Sandy, UT). During graded aerobic capacity tests, ventilation, expired oxygen ( $O_2$ ), and carbon dioxide ( $CO_2$ ) were measured to determine  $VO_2$ ,  $CO_2$  production, and respiratory exchange ratio (RER;  $VCO_2/VO_2$ ). Expired  $O_2$  and  $CO_2$  gas fractions were measured with a paramagnetic  $O_2$  and infrared  $CO_2$  analyzers. Throughout the tests, minute ventilation ( $V_E$ ) was measured via a pneumotachograph (Model 3813, Hans Rudolph Inc, Shawnee, KS), and heart rate (HR; beats/min) was measured with the Suunto memory belt (Suunto Inc, Vantaa, Finland).

**Criteria of maximality:**

Aerobic capacity testing was individualized to the work load (Watts) and progression specific to each participant.(15) Workload was increased every 1 to 2 minutes until volitional exhaustion with a total testing time between 8 to 12 minutes.(15, 19, 26) To ensure attainment of peak exercise, at least three of the following criteria were met: 1) 85% of age predicted maximal HR ( $220 - \text{age}$ ), 2) respiratory exchange ratio (RER)  $>1.1$ , 3) plateau in oxygen consumption despite increasing workload, 4) blood lactate of  $>8$  mmol/L via finger prick (Lactate Plus Meter; Nova Biomedical, Waltham, MA) 60–90 seconds immediately upon aerobic capacity test completion, 5) rating of perceived exertion  $>17$  on the Borg scale of 6 to 20, and, for FES test only, 6) precipitous decline in power  $>20$  Watts despite maximal leg stimulation.(15)

**FESRT:**

All participants performed the same exercise training program within the outpatient hospital exercise facility for 6 months. The hybrid adapted rowing training protocol included three FESRT sessions per week, 20 minutes duration per session, and an intensity progression from 60–70% to 75–90% of  $HR_{peak}$  over 6 months; the training session duration and intensity progression were individualized within these parameters and dependent on both previous and within-session performance.

**Data analysis:**

Peak values ( $VO_{2peak}$ ,  $V_{Epeak}$ ,  $RER_{peak}$ , or  $HR_{peak}$ ) were determined as the highest value obtained from 30-second rolling averages during the graded exercise tests. Univariate normality assumption and homogeneity of variances were verified with the Skewness/Kurtosis test and the Levene's tests, respectively. Variables that violated homogeneity of variances assumptions were converted to logarithmic values. A two-way repeated measure analysis of variance (RMANOVA) with Holm-Sidak correction was used to determine the

change in aerobic capacity (as well as for  $VE_{peak}$ ,  $RER_{peak}$ ,  $HR_{peak}$ , workload, and lactate) by test format (AO, FES), over time (0, 6-Mo) and the interaction between time and test. In addition, a one-way RMANOVA was applied to compare the magnitude of changes in FES rowing  $VO_{2peak}$  over time (0,3,6-Mo). The relationship between changes in  $VO_{2peak}$  during AO vs. FES, as well as correlations between changes in  $VO_{2peak}$  and participant characteristics (age, injury level, time since injury and completeness of injury), were examined using Pearson correlation coefficients. For time since injury (TSI), we kept a homogeneous range of subacute injury (TSI from 0.3 to 2.0 years,  $n = 24$ ) and excluded 3 subjects with chronic injury (respectively 6, 8 and 19 years after injury). Partial eta-squared ( $\eta^2$ ) was calculated to determine the effect size. Reliability of  $VO_{2peak}$  has a coefficient of variation of 4.7–5.7% with the TrueOne2400,(27) so at least 6% increase in  $VO_{2peak}$  (L/minute) in both AO and FES tests was considered an indicator of improved fitness. Based on this indication ( 6% increase vs. all others), we completed sub-analyses of demographic and training characteristics of the two groups with 2-sample t-tests with unequal variance (for normally distributed variables) and 2-sample Kolmogorov-Smirnov exact tests (for those not normally distributed). Analyses were completed using Stata 15 (Statacorp, College Station, Texas).

## Results

### Participants:

Thirty-four participants were enrolled and completed six months of FESRT with baseline and 6-Mo  $VO_{2peak}$  tests. Five of these participants did not complete both testing before and after training and two did not meet criteria for valid  $VO_{2peak}$  tests and were excluded. The remaining 27 individuals were included in analyses below.

Median TSI was 1.2 years (0.4–19.5) and the mean age was 29.8 (6.2) years (Table 1). The most common International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) neurological level of motor was C7 (18.5%), and the ISNCSCI upper extremity motor score (UEMS) of 50 was most prevalent in the sample (30%, Table 1). More than half the participants had American Spinal Injury Association Impairment Score (AIS) of A (55.6%), followed by B and C (each 22.2%). All but one participant were male. Average baseline  $VO_{2peak}$  was low, reaching 18.4 (6.5) mL/kg/min with FES (i.e. 5.3 metabolic equivalent of a task [METs]) and 14.7 (6.0) mL/kg/min with AO (4.2 METs).

### Training adaptations by test format:

As expected when incorporating the lower body musculature into exercise,  $VO_{2peak}$  (L/min) was higher during FES rather than AO row tests ( $\eta_p^2=0.56$ ,  $p<0.001$ ; Table 2). Participants demonstrated increased aerobic capacity ( $VO_{2peak}$ ) after FESRT ( $p<0.001$ ), and changes tended to be greater when assessed with FES than with AO rowing tests (0.15 [0.20] vs. 0.04 [0.22] L/min,  $\eta_p^2=0.03$ ,  $p=0.10$ ; Figure 1). Additionally, improvements in  $VE_{peak}$  were higher with FES compared to AO testing ( $p<0.05$ ). On average, increased  $VE_{peak}$  was observed between FES rowing tests ( $p<0.05$ ), whereas ventilation did not change between AO row tests. There was a general tendency of higher peak workload ( $p<0.001$ ) and peak lactate ( $p<0.001$ ) during FES testing compared to AO testing, but without significant

differences by test over time (Table 2). No changes were found for peak HR in either testing condition.

### Generalization of changes during FES-RT:

Changes in  $\text{VO}_{2\text{peak}}$  during AO correlated with those during FES row tests ( $r=0.55$ ;  $p<0.01$ ; Figure 2). The 11 participants who improved  $\text{VO}_{2\text{peak}}$  by at least 6% (see Methods) on both tests had an average change of 0.27 (0.18) L/min on FES and 0.24 (0.16) L/min on AO row tests. Nevertheless, there was only a partial generalization of training effects for eight individuals who improved  $\text{VO}_{2\text{peak}}$  on FES but not on AO row tests. Those who did not increase  $\text{VO}_{2\text{peak}}$  on both tests had an average change of 0.07 (0.18) L/min on FES and  $-0.09$  (0.13) L/min on AO row tests.

Individuals who increased aerobic capacity on both FES and AO tests were significantly younger than those who showed no generalization of training effects (26.6 [5.6] vs. 32.0 [5.7] years;  $p=0.02$ ). Furthermore, changes in FES  $\text{VO}_{2\text{peak}}$  inversely correlated to TSI in individuals  $<2$  years post-SCI ( $r=-0.51$ ,  $p<0.01$ ,  $n=24$ ) suggesting that those with the best response to FESRT had a shorter TSI. However, no clinical factors (neurological level of injury, UEMS, AIS, TSI) significantly differed between participants with improved AO and FES  $\text{VO}_{2\text{peak}}$  and those without generalized aerobic fitness gains. Furthermore, we found compliance and engagement in training were similar between the groups: no difference was found in average training frequency (session/week), HR, or session duration ( $p>0.30$ ). Participants completed an average of 1.7 (0.5) sessions per week, which is 57% of the prescribed 3 sessions/week, that were 22.2 (6.7) minutes in duration. Average training HR was 119.4 (19.2) beats/min, which was 63 (10) percent of age-adjusted  $\text{HR}_{\text{peak}}$  and 81(7) percent of baseline  $\text{HR}_{\text{peak}}$ .

Lastly, twenty-five of the 27 participants completed 3-Mo FES row tests so this study examined the progression of aerobic capacity over time in FES condition only. There was a significant effect of time on  $\text{VO}_{2\text{peak}}$  ( $F[2,48]=6.8$ ;  $p=0.0025$ ; Figure 3), with average improvements of 7.0% between baseline and 3-Mo ( $p=0.02$ ) vs. 3.9% over months four through six ( $p=0.001$ ).

### Discussion:

Whole body hybrid FESRT led to significant improvements in aerobic capacity among individuals with SCI when evaluated during FES row testing. These findings have potential notable cardiorespiratory health benefits. However, under half of participants had aerobic capacity gains that generalized to work done by the upper body only. Hence, only a subgroup of participants could potentially transfer the benefits from FES row training to daily arms-only (wheelchair-based) activities and this generalization seemed more likely to occur in younger subjects. Greater capacity to reach higher-intensity exercise, higher maximal cardiac output, and greater preservation of upper body muscle mass in younger individuals are potential key reasons for generalization of the gains. Lastly, increases in FES  $\text{VO}_{2\text{peak}}$  were greater during the first three months of training than in the second three months, suggesting that most of the physiological adaptations appear early in training.

Improvements in cardiorespiratory fitness prevent worsening physical health and physical dependence. For example, greater aerobic capacity decreases the risk for all-cause and cardiovascular disease mortality independent of age, ethnicity, and health conditions in able-bodied adults.(14, 28–31) Specifically, a 3 ml/kg/min improvement in aerobic capacity relates to a 15% drop in all-cause and a 19% decrease in cardiovascular disease mortality. (32, 33) Study participants experienced even higher average improvements in their aerobic capacity after FESRT suggesting that they accrued health benefits. Importantly for individuals with SCI, greater fitness is also related to improved mood,(34) higher functional independence,(35, 36) and lower physical strain during daily activities.(21)

The small tendency of greater improvement in  $VO_{2peak}$  when assessed with FES row testing compared to AO row testing underlines the cardiorespiratory benefit of engaging greater muscle mass with FESRT, or in other words, the generalizable fitness effects of FESRT. Though we did not measure cardiac output or muscle composition and cannot conclude the origin of physiological training adaptations, the greater improvement in peak ventilation with FES compared to AO suggests that the addition of the legs led to higher cardiorespiratory engagement in this condition of training and testing. In contrast, the lower-intensity AO test may have precluded observation of ventilatory changes because the cardiorespiratory system was not engaged sufficiently and fewer muscles were activated. If the change in FES aerobic capacity was due solely to central cardiorespiratory improvements, more participants would have shown equivalent improvements on the AO row tests. A study of changes in  $VO_{2peak}$  after robotic body weight supported treadmill training found similar partial generalization to  $VO_{2peak}$  during arm-only cycling (+8.5%,  $p=0.25$ ).(37) In the absence of specific upper body training, researchers attributed this change to possible central cardiorespiratory adaptations. In comparison, the present study trained the arms during FESRT and it is possible that upper body muscular adaptations, peripheral in origin, contributed to improvements in AO  $VO_{2peak}$ .

Improvements in aerobic capacity were greater among younger participants. This finding suggests that a few additional years within a decade of life could limit the cardiorespiratory adaptations of FESRT for some individuals with SCI. Younger individuals are potentially more active and have greater upper body muscle mass, whereas a decline in muscle mass often accompanies aging and the adoption of a more sedentary lifestyle.(38) Such a small difference of 6 years may not be clinically relevant in able-bodied aging but could have implications for upper body muscle structure and function among adults with SCI and subsequent consequences on aerobic capacity gains. Furthermore, within 2 years of SCI the changes in aerobic capacity were greater in those who began FESRT sooner. Though inferences are limited by our small heterogeneous sample, this relationship nevertheless emphasizes a cardiorespiratory merit to whole-body exercise training that begins shortly after SCI.

Lastly, aerobic capacity gains were greatest in the first three months of training. It is possible that participants reached a plateau in aerobic capacity after three months of FESRT and encountered physiological barriers, due to muscle,(39) cardiac,(40) or to ventilatory limits. (1, 26, 40) For example, Qui and colleagues previously reported that after several months of FES rowing, training-related increases in peak aerobic capacity were markedly dependent on

peak ventilation in those with high-level SCI.(26) Improvements in muscle metabolism and/or cardiovascular function after FESRT may outstrip the pulmonary system's ability to generate greater ventilation, and Vivodtzev and colleagues showed that ventilatory support can reverse both  $VE_{peak}$  and  $VO_{2peak}$  limitations in these individuals.(41)

In conclusion, gains in aerobic capacity after whole-body FESRT are better reflected when the testing includes FES in individuals with SCI. Aerobic capacity improvements (+10%) were likely incited by leg activity and cardiorespiratory adaptations that can occur within three months of FESRT. Such improvement in aerobic capacity may lead to considerable implications for cardiovascular health. However, gains in aerobic capacity after FESRT may not generalize to equivalent increases in AO exercise for all participants. Younger adults, potentially because of better preserved upper body muscle function and/or cardiorespiratory function may be more prone to have generalization of FESRT benefits.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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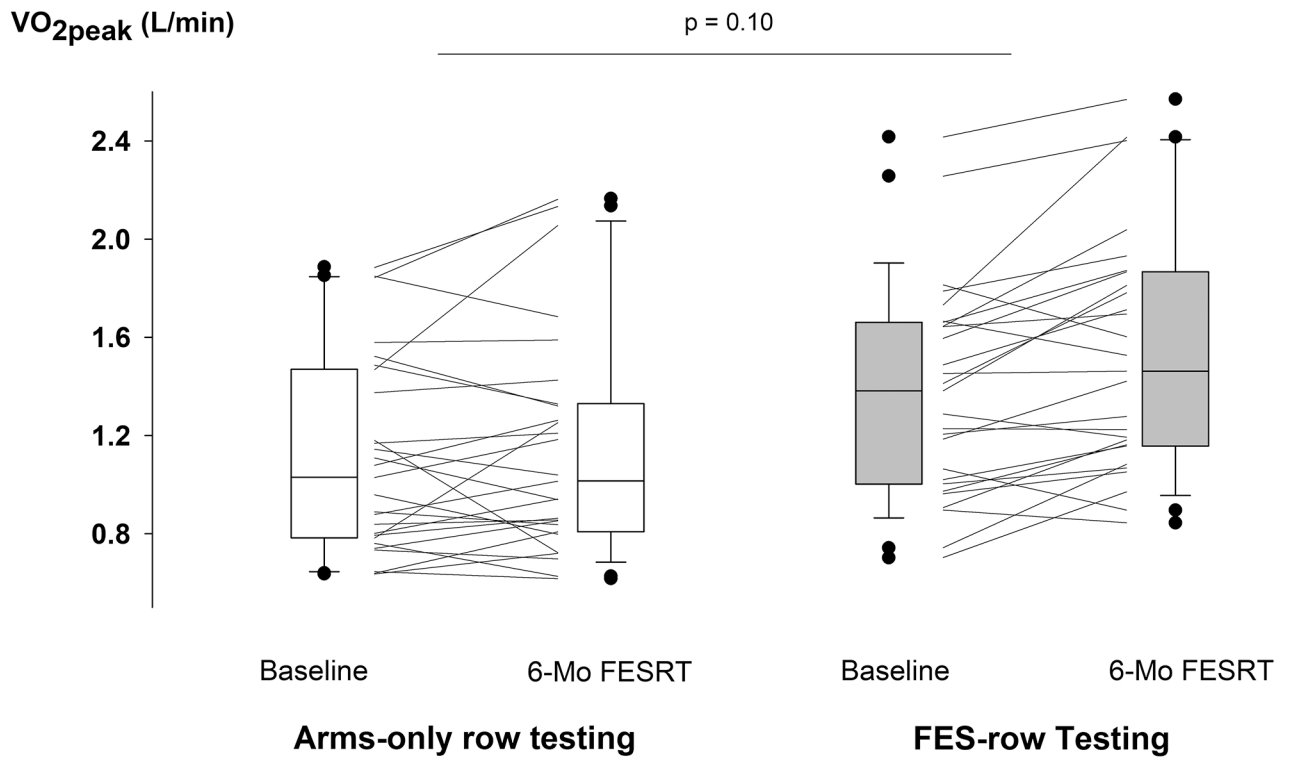
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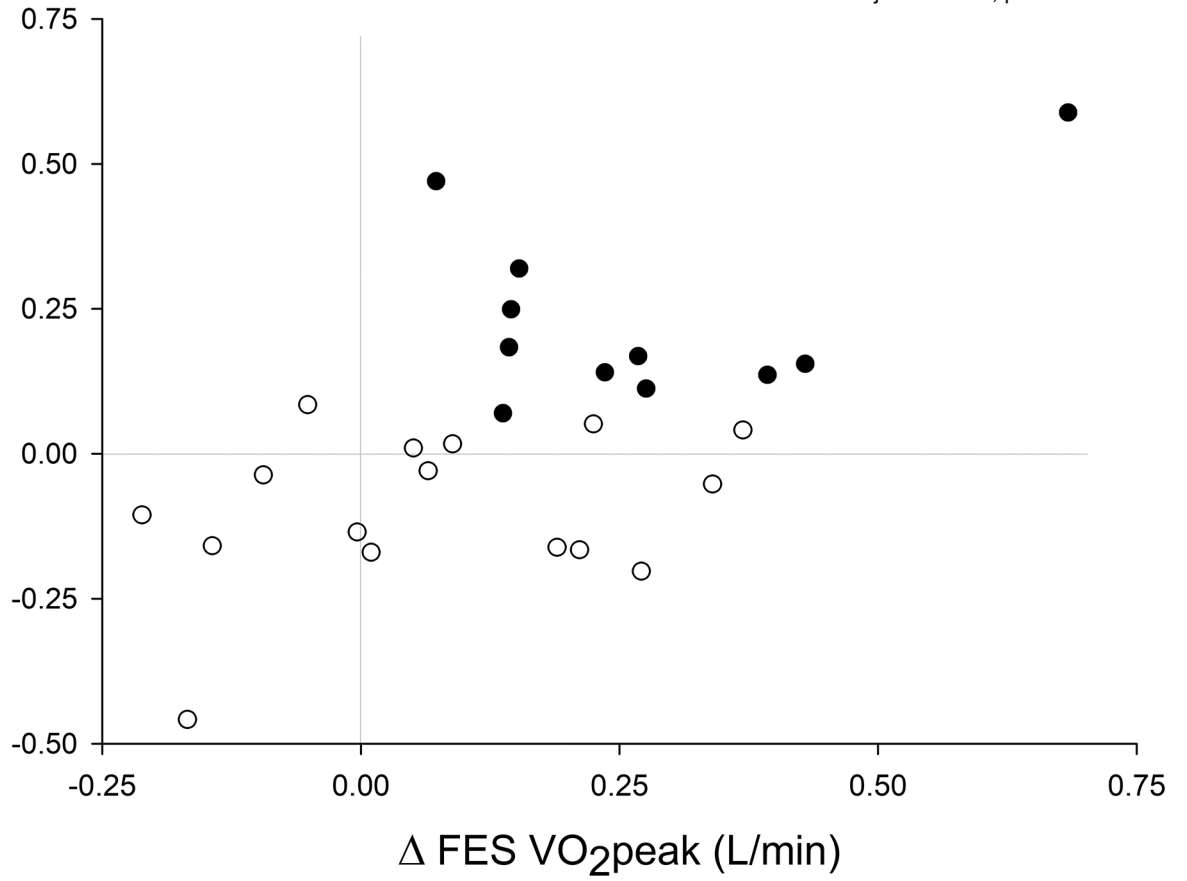
**Figure 1:**

Changes in aerobic capacity after FESRT when assessed with AO or FES row testing

Figure 1 notes: Individual values and box-plot (median, 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles with error bar) of peak aerobic capacity ( $VO_{2peak}$ ) during a maximal incremental exercise using Arms-only row testing (left panel) or FES-row testing (right panel), before and after 6-Mo of FES-row training. The  $p=0.10$  value represents the difference in change of  $VO_{2peak}$  by test format.

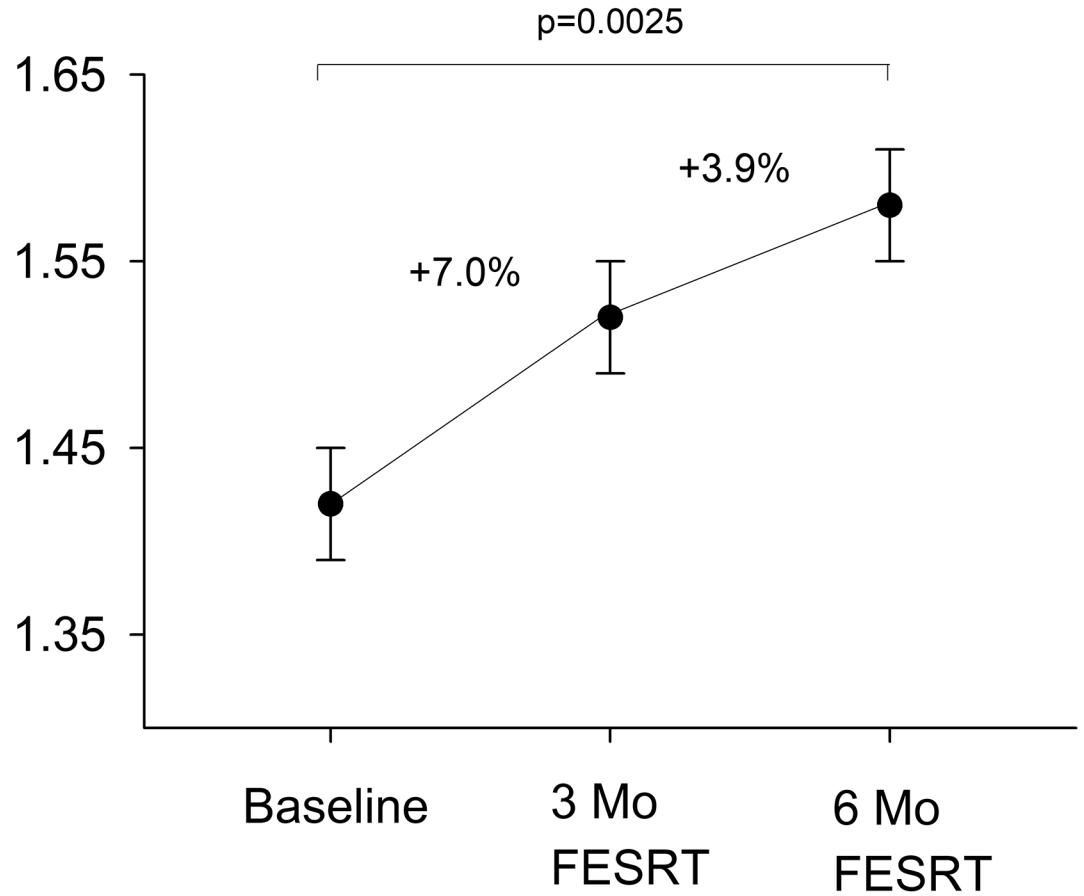
$\Delta$  AO  $VO_{2peak}$   
(L/min)

○ No generalized effects  
● Generalized effects  
All subjects  $r=0.55$ ,  $p=0.003$



**Figure 2.**  
Relationship of change in AO  $VO_{2peak}$  with change in FES  $VO_{2peak}$   
Figure 2 notes: Moderate correlation ( $r=0.55$ ,  $p=0.003$ ) between change in AO and change in FES rowing peak aerobic capacity. Each dot represents one person: Filled (black) circles are individuals who improved  $\geq 6\%$  on both test formats, and open circles are individuals who did not.

## FES row test VO<sub>2peak</sub> (L/min)



**Figure 3.**

Changes in FES VO<sub>2peak</sub> over time

Figure 3 notes: Significant improvements in FES VO<sub>2peak</sub> occurred between baseline and 3-Mo (7.0%;  $p=0.02$ ) and over months four through six (3.9%;  $p=0.001$ ). Nevertheless, increases in FES VO<sub>2peak</sub> were greater during the first three months of training than in months 3–6 ( $p=0.0025$ ), which suggests most of the physiological adaptations appear early in training.

**Table 1.**

Sample demographic and SCI characteristics

Characteristic	N=27
Age, mean (sd)	29.8 (6.2)
Gender, n (%)	
• Male	26 (96)
• Female	1 (4)
TSCI, mean (sd)	2.3 (3.8)
UEMS, n (%)	
• <20	6 (22)
• 20–30	3 (11)
• 31–40	2 (7)
• 41–50	13 (48)
AIS, n (%)	
• A	15 (56)
• B	6 (2)
• C	6 (22)
Neurological Level of Injury (Motor), n (%)	
• Cervical (C4-C8)	15 (56)
• High Thoracic (T1-T6)	9 (33)
• Low Thoracic (T7-T12)	3 (11)
Neurological Level of Injury (Sensory), n (%)	
• Cervical (C4-C8)	14 (52)
• High Thoracic (T1-T6)	8 (30)
• Low Thoracic (T7-T12)	3 (11)

Table 1. notes: UEMS missing for three individuals, and Neurological Level of Injury missing for two individuals. When laterality difference in neurological level of injury present, highest value provided for sensory and motor levels. Abbreviation: UEMS, upper extremity motor score.

**Table 2.**

Physiological values before and after training by test format

Values	AO row test		FES row test		Two-way RMANOVA with post hoc			
	Pre training	Post training	Pre training	Post training	Test format	Time point	Test* Time	
					p-value	n <sub>p</sub> <sup>2</sup>	p-value	n <sub>p</sub> <sup>2</sup>
VO <sub>2peak</sub> L/min	1.11 (0.4)	1.15 (0.5)	1.38 (0.4)	1.53 (0.5)	<0.001	0.56	0.005	0.10
VO <sub>2peak</sub> ml/kg/min	14.7 (6.0)	15.1 (6.5)	18.4 (6.5)	20.2 (7.0)	<0.001	0.60	0.01	0.08
VE <sub>peak</sub> L/min	47.4 (21.4–91.3)	45.4 (20.6–95.4)	49.2 (27.9–80.7)	53.4 (30.7–92.8)	<0.001#	0.13	0.69#	0.01
RE <sub>peak</sub>	1.21 (0.11)	1.15 (0.12)	1.19 (0.09)	1.14 (0.09)	0.42	0.01	0.002	0.12
HR <sub>peak</sub> bpm	142 (32)	143 (36)	149 (25)	150 (27)	0.01	0.08	0.73	<0.01
Lactate mmol/L	8.8 (2.7–20.5)	8.9 (2.7–15.5)	10.3 (7.5–15)	10.8 (5.5–16.4)	0.001	0.32	0.53	0.01
Workload Watts	40.2 (2–114)	47.3 (2–118)	54.3 (15–95)	68.8 (30–135)	<0.001 #	0.27	0.06 #	0.12
RPE	19 (1)	19 (2)	18 (1)	19 (1)	0.40	0.01	0.18	0.02
								0.31
								0.01

Table 2. notes: Physiological values listed are mean (sd) or median (range). Abbreviations: np<sup>2</sup> = partial eta squared, RPE= Borg rating of perceived exertion. #denotes log values used for two-way RMANOVA. Bolded values are statistically significant at alpha=0.05.