

An investigation of the effects of using different numbers of stimulation channels on muscle perfusion during FES-rowing

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Abstract

Functional electrical stimulation (FES) exercise is used by persons with spinal cord injury (SCI) and many different stimulation patterns can be used. It is unknown as to how these patterns affect blood perfusion and so influence fatigue rates. Five SCI volunteers performed 3 minute sessions of FES rowing using 2 stimulation patterns: pattern A using up to 8 channels; pattern B using up to 4 channels. The total haemoglobin (Hbt), oxygenated haemoglobin (HbO₂) and reduced haemoglobin (Hb) were measured using near infra-red spectroscopy (NIRS).

There was found to be significant ($p < 0.05$) differences between the two channel patterns in [Hbt] and [Hb] for all of the subjects. Four of the five subjects showed a highly significant ($p < 0.001$) difference in the [HbO₂]. Using up to 8 channels was found to result in decreased intensity of stimulation required to the rectus femoris, to achieve the same power output.

1 Introduction

FES is a means by which SCI individuals can exercise paralysed muscles. There remain discussions on the optimum number of channels that are most effective in reducing fatigue within the working muscles and thus prolonging exercise time. Neither is it clear which stimulatory patterns produce the optimum sustained power output from paralysed muscles. Both fatigue and power output may ultimately be related to the muscle blood flow. Pournizam *et al.* [1] used power to measure the efficacy of different stimulation patterns. They found that time to fatigue could be increased by spreading the workload over several muscles. Bhambhani *et al.* [2] used NIRS to study muscle deoxygenation in cycling tests and found that there is a decreased amount

of muscle deoxygenation during maximal exercise in SCI subjects compared with healthy subjects. To the author's knowledge there is no published work on muscle oxygenation using different numbers of channels during FES exercise. The aim of this investigation was to determine how using different numbers of channels to stimulate paralysed muscles influences oxygenation within them.

2 Methods

Five subjects were recruited, and subject characteristics are shown in Table 1.

Subject	Sex	Age (yrs)	Level of Lesion	ASIA	Time since injury (yrs)
1	M	52	T4	A	6
2	M	23	T12	A	2
3	M	46	T2/3	A	9
4	M	37	T6	A	8
5	F	25	C5/6	C	12

Table 1: Subject characteristics.

Volunteers were seated in a comfortable, stable position on an adapted Concept 2 rowing ergometer. Adaptations to a standard ergometer included: addition of back and lumbar supports, appropriate shoulder straps adjustable height of the seat position to give a positive tilt of the monorail to allow gravity to aid the rowing motion. Leg stabilisers and foot straps maintained the position of the lower limbs during exercise. NIRS optodes (*Hamamatsu NIRO500*) were securely positioned on the belly of the left rectus femoris.

Stimulation to quadriceps and hamstrings was provided by an Odstock 4 channel stimulator (Odstock Medical, Salisbury UK) set to give 50Hz, 250msec, unramped stimulation. Two Odstock 4 channel stimulators were used to achieve 8 channel stimulation. Stimulation was controlled via a switch on the handlebar of the rowing ergometer.

During regular training subjects used up to 4 channel stimulation with electrodes positioned to primarily stimulate rectus femoris and hamstrings, although radiation to the vastus lateralis is likely to take place.

Each test alternated 3 minutes rest and 3 minutes exercise periods. The first exercise interval used up to 8 channels, the second interval up to 4 channels. For the 8 channel stimulation, electrodes were placed to target vastus lateralis, vastus medialis, rectus femoris and hamstrings in both legs. Some subjects were unable to tolerate 8 channel stimulation for various reasons including abdominal cramping. Subjects 2, 3 and 5 received 8 channel followed by 4 channel stimulation; subject 1 received 6 channel followed by 4 channel stimulation and subject 4 received 4 channel followed by 2 channel stimulation. Changes in blood perfusion, power output and stroke rate were measured.

Statistical analysis of any differences between the power output, stroke rate and [Hbt], [HbO₂] and [Hb] during exercise, using the different channel patterns (pattern A or B), was carried out using paired t-tests. The significance level was set at $p < 0.05$.

3 Results

No significant differences in power output between the two exercise conditions were found. Four of the five subjects showed no significant change in the stroke rate. In one subject a slightly decreased stroke rate was recorded during 8 channel stimulation ($p = 0.04$). It was interesting to note that decreased stimulation intensities were required to produce approximately the same power output when an increased number of channels were used.

Muscle oxygenation was very different between subjects. There were distinct differences in the blood perfusion between subjects and also within an individual subject's results when different numbers of channels were used. Figures 1-5 show each subject's data for total haemoglobin [Hbt], oxygenated haemoglobin

[HbO₂] and reduced haemoglobin [Hb], in order from top to bottom of the graph. The vertical lines represent the start and end of each exercise session. Total sampling time is 900 seconds.

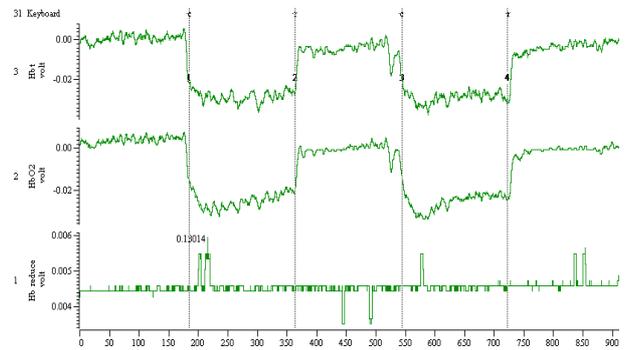


Figure 1: Subject 1; 6channels versus 4channels

During both sessions of exercise [Hbt] and [HbO₂] decreased and then stabilised. [HbO₂] increases towards resting levels during 6 channel stimulation. There are significant differences between the two channel patterns; [Hbt] ($p = 0.05$), and even though there is a very flat line displayed for [Hb] possibly indicating very low values, the difference was still significant ($p < 0.05$). There was no significant difference in [HbO₂] ($p > 0.05$).

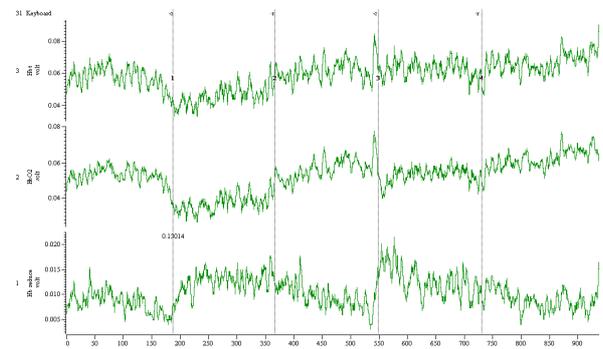


Figure 2: Subject 2; 8channels versus 4channels

All three haemoglobin characteristics change both during and after exercise. The [Hbt] and [HbO₂] initially decrease at the start of exercise but then recover and begin to increase; this new increased level is maintained after the cessation of exercise. [Hb] rises during 8 channel exercise then stabilises. This indicates that perfusion is adequate for this exercise intensity. [Hb] is increased at the start of the 4 channel stimulation exercise but decreases to a level below that seen in the 8 channel stimulation. [Hbt] and [HbO₂] are at a higher level during the 4 channel stimulation than the 8 channel stimulation. When the two channel conditions are compared, differences are significant: [Hbt] ($p < 0.001$), [HbO₂] ($p < 0.001$) and [Hb] ($p < 0.05$) respectively.

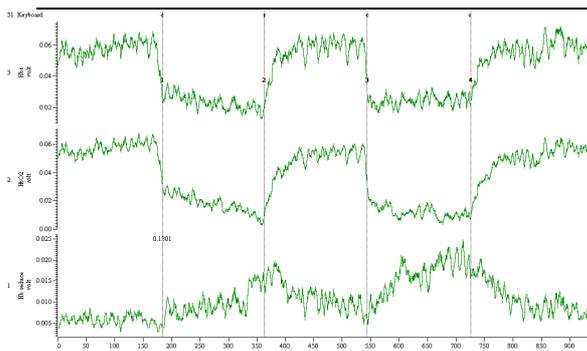


Figure 3: Subject 3; 8channels versus 4channels
[Hbt] and [HbO₂] decreased steadily during 8 channel stimulation. They were steady during 4 channel stimulation. [Hb] increases steeply during the 4 channel stimulation. Fatigue may be evident since [Hb] does not reach the resting level in between the 2 stimulation conditions. The differences in [Hbt], [HbO₂] and [Hb] were all found to be highly significant ($p<0.001$) between the two channel conditions.

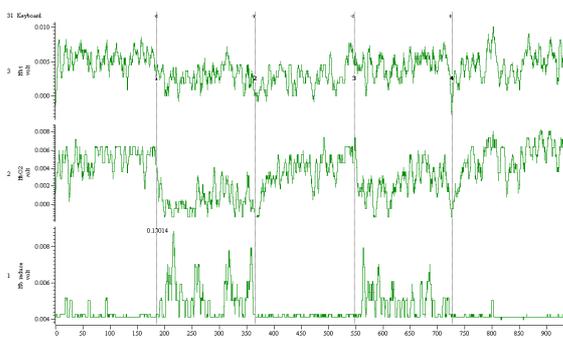


Figure 4: Subject 4; 4channels versus 2channels
The [Hbt] and [HbO₂] are similar to subject 2's in that they increase during 4 channel stimulation. [Hb] is very low during rest periods and increases during exercise. The different channel patterns resulted in highly significant ($p<0.001$) differences, in all the haemoglobin characteristics.

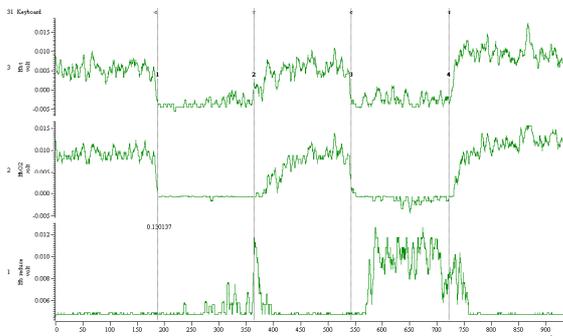


Figure 5: Subject 5; 8channels versus 4channels
During both exercises, [Hbt] and [HbO₂] are steady. However, [Hbt] and [HbO₂] increase above the resting level, after 4 channel exercise. The [Hb] increased significantly during the 4

channel stimulation. [Hbt], [HbO₂] and [Hb] were found to be different during the two channel patterns and these differences were all highly significant ($p<0.001$).

4 Discussion

This investigation provides new insight about oxygenation within paralysed muscles during FES exercise. It is clear that the haemoglobin concentrations are affected by the channel pattern used. It is possible that some sampling from the vastus lateralis may have occurred even though the NIRS probe was placed as accurately as possible on the belly of rectus femoris and this could have affected the results.

Four of the five subjects started on a lower stimulation intensity, in terms of milliamps, delivered to the rectus femoris when a larger number of channels were used. One subject started with the same intensity during both exercise tests. This lower or equal intensity of stimulation, resulted in approximately the same power output as the exercise load was being spread over a larger number of muscles. Increased muscle deoxygenation is seen in the graphs of subjects 2, 3 and 5 (figures 2, 3 and 5) during the second (lower number of channels) exercise session. This may be a consequence of the increased stimulation intensity during this exercise. Two subjects show exercise hyperaemias as increased [HbO₂] and [Hbt]; the mechanism by which these occur remains unclear and further research is required to establish if they are local or central.

These results suggest that using up to 8 channels during FES rowing reduces muscle deoxygenation, which may in turn reduce the rate of fatigue of the muscle.

References

- [1] Pournezam M, Andrews BJ, Baxendale RH, *et al.* Reduction of muscle fatigue in man by cyclical stimulation. *Journal of Biomedical Engineering*, 10: 196-200, 1988.
- [2] Bhambhani Y, Tuchak C, Burnham R, *et al.* Quadriceps muscle deoxygenation during functional electrical stimulation in adults with spinal cord injury. *Spinal Cord*, 38: 630-638, 2000.

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