The Kinematic Effects of Common Peroneal Functional Electrical Stimulation (FES) in Chronic Stroke (CVA) and Multiple Sclerosis (MS) using a 3-D Model of the Shoe

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Functional Electrical Stimulation (FES)

- There is a large FES Clinic (over 500 patients) at the Northern General Hospital Gait Laboratory.
- FES is commonly used in the UK to treat drop foot by stimulating the common peroneal nerve to correct excessive plantarflexion during swing.
- FES is also commonly prescribed to improve stability at initial contact and/or forefoot clearance in swing, in the presence of excessive inversion.
- FES has been shown to improve walking speed although there has been little published that show direct 3-d kinematic improvements with FES.
Functional Electrical Stimulation (FES)

Without FES:     With FES:

• VIDEOS NOT AVAILABLE
Direct and Indirect effects of FES

Direct Effects of FES:
• Increased DF in swing
• Increased eversion (correction of excessive inversion)

Indirect effects of FES:
• Increased Speed
• Reduced fatigue when walking
• Reduced tripping and falling
• Increased Confidence
• Less associated reactions
Common clinical outcome measurements in FES clinics include:

- Speed (light gates, stopwatch)
- average step length (steps between 2 markers)
- Physiological Cost Index (PCI)
- DF/PF from PiG

These measurements excellent clinical OMs BUT they do not always “tell the full story”…
The problem with Speed – no FES
Functional Electrical Stimulation (FES)

With FES:

• VIDEOS NOT AVAILABLE
The problem with Speed – FES on
The problem with Speed

FES was successful - Why?

• He felt his walking was easier. (indirect)
• He felt safer, more confident that his foot wouldn’t “tip” over during stance (indirect)
• Correction of excessive inversion during swing. (direct)

BUT the speed was the same with the FES on vs off.
The problem with Speed

Gait kinematics can be improved without a change/improvement in speed.

As you get faster you approach a normal range.

- A 10% increase in speed for someone who walks 0.9 m/s (close to the normal range) is different than a 10% increase in speed in someone who walks 0.08 m/s. The slower person has the most scope to improve.
Problems with other OMs

Energy Expenditure Measures (PCI, THBI, Borg):

• Quantifiable measurements (PCI, etc) need a “steady state”. Can you be confident that you’ve eliminated order effects with someone who suffers from fatigue.

• Subjective measurements (Borg) rely on patients understanding of the question.
Problems with DF/PF 3-d gait analysis

Standard 3-D clinical gait analysis models (i.e. PiG) the foot as a vector and consequently:

- Can get a measurement of DF/PF and foot progression (and foot rotation compared to knee axis)
- No measurement of inversion/eversion.
- More complex foot models (Oxford Foot Model) that measure in/eversion require the patients to be barefoot.
- CGA takes a long time – often unsuitable to do clinically.
Shoe Model (Emma Pratt)

- Develop a simple model (2 extra markers on medial aspect of 1\textsuperscript{st} met. head and lateral aspect of 5\textsuperscript{th} met head)
- Attempt to validate.
Shoe Model validation

- Preliminary Validation – Used 11 Normal subjects (22 feet), barefoot with OFM 3D barefoot model (Stebbins et al, 2006)
- Used virtual distal 1\textsuperscript{st} met head marker, 5\textsuperscript{th} met head marker to represent shoe model.
- Good correlation of shoe model inversion and eversion compared to validated OFM.

![Graphs showing DF/PF and Inv/Eve comparison between Shoe Model and OFM validation.](image-url)
To look at the Direct kinematic effects of FES we borrowed full 3-d data (including shoe model) from another study (ShefStim):

- Cohort of existing unilateral FES users at STH (n=20, n=9 CVA, n=11 MS).
- Patient-selected footwear.
- Self-selected normal speed.
- 8 Vicon MXF40 cameras (Vicon Ltd, Oxford UK) capturing at 100Hz.
- Electrode sites and the pulse width were selected by the patient to reflect their usual response.
- Two representative traverses were completed with both FES on and off (randomised order).
Materials and Methods

Direct kinematic Outcome Measures:

- DF/PF at initial contact.
- maximum DF in swing.
- inversion/eversion at initial contact.
- inversion/eversion in mid-swing.

For both MS and CVA groups, the non-parametric Wilcoxon test (level of significance $p \leq 0.05$) was calculated to investigate the null hypotheses of no difference with or without stimulation.
Results – walking speed

Median speed (25th-75th percentile) was calculated from 3D data:

- **MS (n=11)**
  - = 0.60m/s (0.37-0.96) without FES
  - = 0.63m/s (0.52-1.10) with FES

- **CVA (n=9)**
  - = 0.70m/s (0.41-0.80) without FES
  - = 0.74m/s (0.63-0.90) with FES.
Results – Shoe Model

MS group (solid trace with FES, dashed trace without FES)

CVA group (solid trace with FES, dashed trace without FES)
Results – Shoe Model

- 3-D kinematics with FES applied:
  - increased dorsiflexion during swing.
  - reduced inversion during swing.
  - Improved ground clearance.
  - Improved pre-positioning of the foot at initial contact.
- Improvements in the coronal plane were only statistically significant for MS patients, perhaps due to the variable and often increased tone seen in the CVA population.
- The ‘shoe model’ was helpful when performing 3d gait analysis of patients with footwear donned.
- Paper submitted to Gait and Posture.
Conclusions

- People improve in different ways with FES (ie faster, improved kinematics, less effortful walking)
- Difficult to find outcome measures which characterise the effects of FES with a non-homogeneous group.
- Indirect outcome measures are appropriate in a clinical context and are secondary to the direct effects.
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• Patient of the Sheffield FES service who volunteered

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