Using FES for foot drop may strengthen cortico-spinal connections

Everaert DG\textsuperscript{1}, Thompson AK\textsuperscript{2}, Chong S\textsuperscript{1} and Stein RB\textsuperscript{1}

\textsuperscript{1} Centre for Neuroscience and Department of Physiology, University of Alberta, Edmonton, Canada
\textsuperscript{2} Wadsworth Center, N.Y. State Department of Health, Albany N.Y., U.S.A.

everaert@ualberta.ca

Abstract

Eight subjects with chronic foot drop (>1 year) from a variety of CNS causes were measured before and after using FES while walking in the community for a minimum of 3 months. All but one subject increased their walking speed, even when the FES unit was off, and 4 of 9 legs (one subject used FES bilaterally) showed an increased maximum motor evoked potential (MEP) in the tibialis anterior muscle from transcranial magnetic stimulation (TMS) of the cortex. Subjects with a decreased MEP did not increase their walking speed more than about 20%, whereas those who increased their walking speed 30% or more had increased MEPs. Since short term stimulation of a peripheral nerve is known to increase the excitability of cortico-spinal pathways transiently, we suggest that continued FES consolidates these increases and leads to improvements in walking speed even when the FES is not in use.

1. INTRODUCTION

In their initial report on the use of electrical stimulation for correcting foot drop during walking, Liberson et al. [1] noted that some people who used the stimulation improved their function even after the stimulation was turned off. This “carry-over” effect has been noted many times subsequently. For example, Wieler et al. [2] reported that walking speed increased 45% after about a year using a foot drop stimulator, whereas the speed increased 20% in the same task when the stimulator was turned off. There could be several explanations for this finding. Electrical stimulation is well known to strengthen muscles (e.g., [3]), so speed could be increased because of stronger muscles. The increase in walking speed is proportional to the increase in steps taken daily with stimulation [4], so the locomotor circuitry in the spinal cord could also be facilitated. Finally, the residual, descending connections from the brain to the spinal cord could be strengthened.

Previous work has shown that 30 minutes of FES-like common peroneal (CP) nerve stimulation increases the corticospinal excitability of the tibialis anterior (TA) muscle, as tested by TMS, for an hour or more [5, 6]. Recently, Stein et al. [4] reported on a single patient with a long-standing head injury (19 years), who nearly doubled his walking speed over a period of a year using FES while walking. He also showed a comparable increase in the motor evoked potential (MEP) recorded in the TA muscle from stimulating the motor cortex with TMS. This suggests that at least some of the improvement with FES arose from strengthened cortico-spinal connections, as well as strengthened muscles and spinal circuits. This paper provides more evidence for this suggestion in a group of 8 patients.

2. METHODS

Eight subjects who had no contra-indications for TMS were measured before and after at least 3 months of using the WalkAide (WA) foot drop stimulator regularly (WalkAide; Innovative Neurotronics, Bethesda MD). The WalkAide stimulates the CP nerve to activate the TA muscle during the swing phase of gait. Stimulation is turned on and off by a built-in tilt sensor (see [4]). Subjects were adults (35-73 years old) and had a variety of conditions, which had existed for 2.5 to 39 years, see Table 1. One subject with hereditary spastic paraparesis (HSP) used a WA on both legs. For another subject, the exact cause of the foot drop was unknown, as it
occurred after knee surgery and became worse as a result of decompression sickness after scuba diving.

EMG electrodes were placed over the TA muscle and the maximum voluntary contraction (MVC) was measured as described previously [6]. During TMS, subjects were asked to contract at a level of 15-20% of MVC, as monitored on an oscilloscope. An MES-10 stimulator (Cadwell, Kennewick WA) was used with a double-D coil. A centimeter grid was placed over the subjects scalp for mapping with the origin of the grid at the vertex of the head. The coil was first moved in cm increments to find the location that consistently produced the best response. Then, the stimulus was increased in 10% steps to find the threshold and the level of TMS that produced maximal and half-maximal responses based on the input-output (IO) curve. Finally, a TMS level that produced at least a half-maximal response was used to map the motor cortex from the vertex/midline to 3 cm lateral, anterior and posterior. Four stimuli were applied at each of 25 positions. The MEPs were quantified by calculating peak-to-peak (PP) and mean rectified (MR) values for the time window in which the response exceeded the background level of voluntary contraction. The ratios (after/before) of maximum PP and MR MEPs from the IO curve and the 4 highest values from the mapping were averaged into an overall MEP ratio by taking the geometric mean.

3. RESULTS

Fig. 1 shows data from a subject who had a stroke when he was only 17 years of age and who entered the FES program nearly 40 years later. He could walk at a fairly good speed (1.2 m/s), but with an obvious foot drop. The WalkAide foot drop stimulator produced an immediate small increase in walking speed, but over 6 months of use the speed increased to about 1.4 m/s. A small difference persisted in speed with and without the WA. After 6 months he found that he could maintain the gains he had made only using the stimulator every few days and this was verified when he was retested after using FES for more than a year.

Fig. 1 also shows that the MVC and the maximum peak-to-peak MEP both increased substantially. The final panel of Fig. 1 shows data after 1 month of FES, when the walking speed and MEP had not yet increased substantially. The MEP was measured before and after two 15 min. periods of FES with walking. Over this brief period the MEP increased to the level it eventually reached after 6 months of FES. The MEP remained at this level for at least 30 minutes following stimulation, but presumably declined subsequently to the initial values. We suggest that this transient increase during brief periods of walking with FES was gradually consolidated and retained as the subject walked regularly with FES over the following months.

Not all subjects showed such large changes as subject GG above. Table 1 shows data from 9 legs in 8 subjects (see Methods). After 3 to 13 months of WA use, all but one subject increased walking speed, whereas increased MEPs and MVCs were measured in only 4 and 6 of the 9 legs respectively. Walking speed, even with the
WA off, increased on the average 22% (-6 to 79%), while MVC increased 33% (-60 to 117%). Although limited to 4 subjects, the increases in MEP were substantial, ranging from 13 to 91%. Figure 2 shows that the change in walking speed was correlated (r^2 = .54) with the change in maximum MEP. The data suggests that subjects can increase their walking speed by up to about 20% without an increased MEP, but the larger increases of 30 and 80% were accompanied by increases in MEP. The correlation was weakened by subject GG, who showed the second largest increase in MEP of 75% while his walking speed only increased by 16%. This subject was already walking fast when entering the trial, and could therefore not improve much in speed. Nevertheless, his gait improved in quality. With a 117% increase in TA MVC, he re-gained active control over ankle dorsiflexion, resulting in a better gait pattern.

### 4. DISCUSSION

To our knowledge this is the first study to correlate changes in walking speed with changes in motor evoked potentials in subjects with chronic foot drop that was treated for more than 3 months by FES. The number of subjects is still small, but our data suggest that subjects showing substantial increases in walking speed also show increased TA MEPs (see also [4]). Other subjects showed little change or even a decrease in maximum MEP and we do not yet know what factors determine the outcome. We doubt that the etiology of the foot drop is the main factor as the two subjects showing the largest change had different causes of their foot drop (head injury and stroke). The time since the onset of the condition not likely to be crucial, since these subjects had their condition for 19 and 39 years respectively. Further study of a larger group of subjects with foot drop from various causes might provide some clues about contributing factors and causes.

### References


<table>
<thead>
<tr>
<th>Subj</th>
<th>Cond</th>
<th>Age (yrs)</th>
<th>Onset (yrs)</th>
<th>FES (mo)</th>
<th>MEP (%)</th>
<th>MVC (%)</th>
<th>Vel (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN</td>
<td>SCI</td>
<td>51</td>
<td>33</td>
<td>6</td>
<td>-8</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>EM</td>
<td>stroke</td>
<td>67</td>
<td>2.5</td>
<td>5</td>
<td>-6</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>JL Le</td>
<td>HSP</td>
<td>54</td>
<td>12</td>
<td>4</td>
<td>13</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>JL Ri</td>
<td>stroke</td>
<td>73</td>
<td>4</td>
<td>6</td>
<td>-10</td>
<td>108</td>
<td>-6</td>
</tr>
<tr>
<td>CB</td>
<td>MS</td>
<td>37</td>
<td>9</td>
<td>11</td>
<td>-17</td>
<td>-60</td>
<td>16</td>
</tr>
<tr>
<td>JY</td>
<td>unkn</td>
<td>35</td>
<td>10</td>
<td>4</td>
<td>26</td>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>GG</td>
<td>stroke</td>
<td>57</td>
<td>39</td>
<td>5</td>
<td>75</td>
<td>117</td>
<td>16</td>
</tr>
<tr>
<td>ML</td>
<td>TBI</td>
<td>43</td>
<td>19</td>
<td>13</td>
<td>91</td>
<td>-52</td>
<td>79</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>52</td>
<td>16</td>
<td>6.3</td>
<td>18</td>
<td>33</td>
<td>22</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>14</td>
<td>13</td>
<td>3.3</td>
<td>39</td>
<td>71</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 1. Onset of condition; FES, months of WA use; percent change before-after WA use in MEP, MVC, velocity (Vel) of walking without WA.