Potential application of a passive cycling training as a tool for modulating spinal H-reflex pathways in post-acute stroke patients: a feasibility study

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Abstract

It has been demonstrated that passive cycling training can modulate the H-reflex spinal pathways in an animal model with complete spinal cord transection and in humans with complete spinal cord injury. The aim of this study was to understand if a similar modulation can be induced in hemiparetic patients. This aspect can be crucial in stroke rehabilitation because a recalibration of activity in the H-reflex pathway may be one possible strategy for the recovery of functional locomotor activity. A 5-days passive cycling training was defined, and specific functional (Motricity Index and voluntary cycling on a sensorized ergometer) and physiological tests (soleus H-reflex post-activation depression) were carried out in 2 stroke patients before and after the training in both legs. In the paretic leg, there was a significant increment in the H-reflex and in the homosynaptic depression. In the non-affected leg, there was a significant reduction in the amplitude of the H-reflex and in its post-activation depression. The latter outlasted the period of training. Thus, the application of the passive cycling training was associated with a persistent modulation of spinal pathways in the healthy leg. A functional improvement was observed in both lower limbs.

1 Introduction

The recovery of motor function in individuals with stroke depends on the severity of the lesion but also on the choice of the rehabilitation treatment. Spasticity, a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, is a common complication after stroke. Most of the recovery is achieved in the first 6 months following the stroke (post-acute period) and it is due to the plasticity of the central nervous system. There is growing evidence that the spinal cord can express use-dependent plasticity [1], strongly correlated to the nature of training [2]. In humans the existence of spinal use-dependent plasticity has been inferred by modifications in the size of the H-reflex [3]. The H-reflex is a physiological response of muscles after electrical stimulation of sensory fibers in their innervating nerves. It is mediated by a monosynaptic pathway that includes the Ia afferent neuron, its synapse on the α-motor-neuron, and the α-motor-neuron. A repetitive activation of the Ia afferent pathway can lead to reductions in neurotransmitter stores, and thus neurotransmitter release at the α-motoneurons [3]. This reduction, called homosynaptic depression (HD), affects the H-reflex reducing its amplitude. Among the many possible mechanisms responsible for increased stretch reflex excitability, a reduced HD may have a functional correlate in spasticity [1]. There is evidence for restoration of H-reflex post-activation depression by a passive cycling exercise regimen in an animal model with complete spinal cord transection and in humans with complete spinal cord injury [4]. The potential application of cycling as a tool for locomotor recovery after motor lesions has been very recently reported [4]. It is not known if a passive cycling training could induce modulation of the H-reflex pathway in patients with stroke. This is important because a passive cycling training could be applied at an early stage after stroke in patients with reduced locomotor and cognitive function such as to make active/skillful training difficult to perform [2]. The aim of our study was to understand if passive cycling training could modulate the soleus H-reflex and HD in the healthy and paretic leg of stroke patients. The possibility of identifying a type of training able to induce a spinal pathway modulation and to re-
duce spasticity may be crucial in the choice of a suitable rehabilitative training for individuals with stroke.

2 Methods

2.1 Patients

After giving a written informed consent, 2 hemiparetic patients were recruited for the experiments. Details of patients are reported in Table 1.

<table>
<thead>
<tr>
<th>Sub</th>
<th>Sex</th>
<th>Age</th>
<th>Ictus (H/I)</th>
<th>Paretic side (L/R)</th>
<th>Days Post-Ictus</th>
<th>Ashworth scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>F</td>
<td>33</td>
<td>H</td>
<td>L</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>P2</td>
<td>M</td>
<td>44</td>
<td>I</td>
<td>L</td>
<td>74</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1 Patient details. The ictus origin is hemorrhagic (H) or ischemic (I), while the paretic side is left (L) or right (R). Plantar flexor spasticity is measured by the Ashworth scale (0-4).

2.2 Cycling training

The training protocol consisted of 5 sessions. During each session, lasting 16 minutes, the patient was asked not to contribute voluntarily to passive pedalling on a motorized cycle-ergometer, THERA-live™, (Medica Medizintechnik GmbH, Germany) which maintained the speed at a constant value of 30 rpm. During the 5-days of the protocol, the patients performed also their standard rehabilitation protocol.

2.3 Pre- post-training tests

The following tests were carried out in order to assess the motor recovery of the patients:

1. Motricity Index (MI) of the paretic leg;
2. voluntary pedalling against a fixed pedal resistance. The trial lasted 90 s: during the first 30 s, passive pedalling at a constant cadence of 25 rpm was performed; in the last 60 s, the patient was asked to pedal voluntarily. During this trial, the angular velocity and the torque produced at the right and left pedal were measured.
3. the measure of the Soleus H-reflex of both the legs. EMG was recorded from the soleus; surface electrodes were applied in a bipolar configuration with the active electrode 4 cm below the inferior margin of the two heads of the gastrocnemius muscle and the reference one over the Achilles tendon. H-reflexes were acquired after stimulation of the tibial nerve at the popliteal fossa. For each subject, the stimulus duration was 1 ms and the stimulus intensity was adjusted at the beginning of the session to elicit an M response equal to about 5% of the maximum M response ($M_{max}$). Twelve trials were carried out; each trial included a train of 5 pulses with an inter-pulse interval of 1 s. Between 2 trials, we waited for 15 s, at least. Thus, the first H-reflex of each train ($H_1$), was the control response, while the subsequent sweeps ($H_{2-5}$) revealed the HD phenomenon. All the described tests were executed two days before and after the training; the H-reflex test was performed also soon after the first and the last day of training.

2.3.1. Data Analysis and Statistics

In the active phase of the voluntary pedalling test, the mean velocity and the mean value per revolution of the power output (PO) produced by the 2 legs at the right and left pedal were computed.

During the H-reflex test, the following parameters were computed:

- $H size$ defined as $H_{pp}/M_{max}$, i.e., the ratio between the first H-reflex amplitude obtained in the first pulse of each trial ($H_{pp,1}$ in Fig. 1) and the $M_{max}$ amplitude.
- $HD$, i.e. the $H_{pp}$ reduction, computed as follows:
  \[ HD = \frac{H_{pp,1}}{H_{pp,5}} \]

Fig. 1 M wave and H-reflex recorded from the healthy limb of P2 after the 1st and 5th pulse of a single train.

The $H size$ and $HD$ data were not normally distributed (Kolmogorov Smirnov test, $p=0.05$). Therefore, a non parametric Kruskal Wallis statistical test ($p=0.05$) was performed to evaluate differences in values of $H size$ and $HD$ before, during and after training. Post hoc Dunn-Sidak test evidenced the difference between each couple of tests.

3 Results

The two patients showed similar behaviours in terms of $H size$ and $HD$ response. All the results are representative of P2.

$H size$ in the “healthy” limb (Fig 2 (a)) shows a significant reduction soon after the first day of training which is maintained throughout. The time course of $HD$ (Fig 2 (b)) dropped to a significant level 2 days after the end of training. $H size$ in the paretic limb (Fig 2 (c)) highlights a significant increase after the first acquisition. $HD$ changed significantly in the last acquisition with respect to the second and third measurement (Fig 3 (d)).
Fig. 2 Changes in $H$ size and $HD$ are shown for the healthy leg (panels (a) and (b), respectively) and paretic one (panels (c) and (d), respectively) for P2. Asterisks indicate statistical significant differences (Dunn-Sidak post hoc test; $p<0.05$).

The results obtained in the functional pre and post training tests are reported in Table 2. In both patients the increase of $MI$ was due to improvement in the activity of proximal muscles (acting at the knee and hip joints).

Table 2: Results of the pre (grey) and post (white) tests.

<table>
<thead>
<tr>
<th>Sub</th>
<th>MI</th>
<th>Mean PO [W]</th>
<th>Mean Velocity [rpm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Healthy Leg</td>
<td>Paretic leg</td>
</tr>
<tr>
<td>P1</td>
<td>39</td>
<td>2.7±2.0</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2±2.5</td>
<td>1.9±1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26.7±2.5</td>
<td>32.2±2.3</td>
</tr>
<tr>
<td>P2</td>
<td>44</td>
<td>15.3±0.8</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.0±2.7</td>
<td>5.9±1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27.4±1.8</td>
<td>35.0±1.8</td>
</tr>
</tbody>
</table>

The voluntary cycling trials of P2 are shown in Fig. 3. In the active phase (30-90s) the mean PO produced by both legs increased after the 5 days of training. The left mean PO in the post test was always greater than 5 W (the double of the values obtained in the pre test).

Fig. 3 The mean PO per revolution produced by both the legs of P2, during the voluntary cycling carried out before (a) and after training (b).

4 Discussion

After 5 days of passive cycling there was a significant reduction in $H$ size and $HD$ in the healthy side. This means that the training was presumably effective in modulating the H spinal pathways in the healthy limb. The same was not observed in the paretic side. The reasons could be twofold: a too short duration of training (5 days) and/or excessive spasticity of the plantar-flexor muscles.

The $MI$ and voluntary cycling tests reflect a measure of the whole lower limb function and showed an improvement in both legs. The functional improvement in the paretic leg is not reflected in the H-reflex measure. This is probably because the partial recovery of strength is mostly related to greater activity in the more proximal musculature.

However, it is also possible that a modulation of the H-reflex spinal pathway of the healthy side after training may have influenced the partial functional recovery of the impaired side. This is coherent with the notion that pedalling of the healthy side may help the functional recovery of the affected one [5].

5 Conclusion

Passive cycling training was associated with a persistent modulation of the soleus H-reflex spinal pathway in the healthy leg of stroke patients. The lack of similar results in the paretic limb may call for some modifications of the training protocol: probably a longer training is needed in spastic limbs. In addition, it may be helpful to use an isotonic passive training at different speeds in order to introduce a greater variation of muscle dynamics and thus of somatosensory input. Passive cycling training could be a potentially useful, low-cost tool, as an adjunct to other approaches, for the recovery of locomotor function in stroke patients.

6 References