Modulation of soleus H-reflex following ipsilateral mechanical loading of the sole of the foot in normal and complete spinal cord injured humans

Maria Knikou¹, Bernard A. Conway*

Bioengineering Unit, University of Strathclyde, G4 0NW Glasgow, Scotland, UK

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Abstract

The modulation of the soleus H-reflex in response to tonic mechanical loading applied to the plantar aspect of the foot sole was examined in nine normal subjects and five patients with a clinically defined complete spinal cord injury (SCI). With the subjects seated, tonic pressure applied to the metatarsal region of the ipsilateral foot sole significantly depressed soleus H-reflex excitability in all subjects. The demonstration of a decrease in H-reflex excitability in both subject groups as a result of applied pressure to the foot suggests that the change in reflex excitability is the result of a common spinal mechanism. The results highlight the modulatory effects that natural stimulation of cutaneous afferents can have on reflex excitability and may have practical application in gait rehabilitation and in the management of disorders of muscle tone following SCI. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Spinal cord injury; H-reflex; Cutaneous afferents; Natural stimulation; Human; Motor control

Mechanoreceptors from the foot sole are likely to play a role in the reflex regulation of normal posture and gait and may provide an important source of phasic sensory feedback during treadmill assisted gait training following spinal cord injury (SCI). In this context studies using electrical stimulation of cutaneomuscular afferents from plantar nerves demonstrate the existence of complex synaptic actions on active ankle muscles [2]. Moreover, a short latency inhibitory pathway to ankle extensors following low threshold stimulation to the posterior tibial nerve is enabled in normal subjects when the foot sole contacts a surface [1]. It is also recognized that non-nociceptive stimulation of plantar afferents during gait evokes phase dependent cutaneomuscular reflexes in limb muscles [11,13] and that this form of stimulation can depress the modulation of the soleus H-reflex seen during walking [4]. Although the normal pattern of reflex modulation during gait in ambulatory SCI subjects is lost, certain phase dependent reflex effects associated with plantar nerve stimulation can still be recognized. For example, plantar nerve stimulation can evoke an inhibitory reflex in soleus during stance and has been shown to reduce soleus H-reflex excitability during the early stance and swing phases of gait in ambulatory SCI subjects [4,8]. Collectively, considerable evidence therefore suggests that feedback from the foot sole can influence spinal reflex pathways in normal and SCI subjects. However, given the nature of electrical stimulation it remains unclear whether the asynchronous activation of cutaneous mechanoreceptors from the foot sole during ground contact either in standing or walking exerts a measurable effect on spinal reflexes in normal or spinal cord injured subjects. Accordingly, the current set of experiments were performed to test if afferent feedback resulting from tonic pressure applied to the ipsilateral sole of the foot in normal subjects and those with a complete SCI altered the excitability of the soleus H-reflex. Part of this study has been published in abstract form [3].

Experiments were conducted with local ethical committee approval (Southern General Hospitals NHS Trust, Glasgow, UK) and the informed consent of all participants. Nine normal adult males (age 23–38 years) and five male SCI subjects with thoracic lesions participated. All SCI subjects were considered to be motor complete on the basis of clin-

* Corresponding author. Tel.: +44-141-5483316; fax: +44-141-5526098.
E-mail addresses: m-knikou@nwu.edu (M. Knikou), b.a.conway@strath.ac.uk (B.A. Conway).
¹ Present address: Northwestern University Medical School, Department of Physical Medicine and Rehabilitation, Rehabilitation Institute of Chicago, Sensory Motor Performance Program, 345 East Superior Street, Suite 1406, Chicago, IL 60611, USA.
The depression of the H-reflex was apparent in all the SCI subjects and the conditioned reflex was significant at a 95% confidence interval or better (P < 0.05). In the normal subject group, the H-reflex was reduced to between 88 and 23% of control values with load-

![Fig. 1](image-url)

**Fig. 1.** (a) The average H-reflex (n = 20) recorded under control (dashed line) and loaded conditions (solid line) in a normal subject and (b) in a spinal cord injured subject. Note that the reduction in H-reflex amplitude in the loaded condition for both subjects occurs without significant changes in M-wave.

Summary details of SCI subjectsa

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Age (years)</th>
<th>Injury level</th>
<th>Duration of injury (yrs)</th>
<th>Ashworth score at ankle</th>
<th>Medication</th>
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<td>1</td>
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<td>T₇₈</td>
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<td>T₅₆₇</td>
<td>8</td>
<td>0</td>
<td>None</td>
</tr>
</tbody>
</table>

a The spinal lesions in all subjects were a consequence of trauma. In subjects 1, 2, 3 and 4 the lesions were considered to be motor and sensory complete on the basis of clinical examination. For subject 5 clinical assessments revealed a complete motor lesion with preserved joint sensation arising from the first toe of the right foot.
ing, whilst in the SCI group the reflex was reduced to between 59 and 24% of control values (see Fig. 2).

For all subjects a minimum of two loading conditions were examined. However, for two normal subjects (subject 2 and 5) and one spinal cord injured subject (subject 2) three different loading conditions were tested. By testing different loads it was hoped to identify if changes in reflex size varied systematically with the magnitude of the applied load. For simplicity in data presentation the loads tested are categorized into three pressure ranges (10–25 kPa, 25–40 kPa, 40–55 kPa) and the resultant mean size of reflex observed under these loading conditions is plotted in the histogram shown in Fig. 2. From an inspection of Fig. 2 it is apparent that no clear or consistent relationship between the magnitude of the applied load and the degree of depression of the H-reflex can be recognized within either the normal or SCI groups despite the clear reduction in size of the reflex at all loads for all subjects. It would therefore appear that load applied to the metatarsal region of the foot sole depresses H-reflex excitability in normal and SCI subjects but that the depression observed is not a simple function of the magnitude of the applied load.

Pressure applied to the foot sole will activate many types of cutaneous mechanoreceptors resulting in widespread and mixed oligosynaptic actions. However, it is interesting to note that while localized brushing of the skin overlying the soleus muscle can reduce H-reflex excitability [12] similar stimulation to the foot sole results in a decrease in presynaptic inhibition of soleus Ia afferents [7]. Thus it is likely that the superficial cutaneous receptors activated by brushing the foot sole do not contribute to the present findings. Accordingly, it would seem likely that slowly adapting subcutaneous mechanoreceptors mediate the inhibition of the soleus H-reflex. The involvement of receptors with wide receptive fields, such as Ruffini corpuscles, might also partly explain the lack of a clear relationship between the magnitude of the applied load and the degree of H-reflex inhibition seen in this study. During standing, the size of the soleus H-reflex is depressed when compared to that observed during sitting [6,9] and although the current data should be interpreted cautiously with respect to standing it is probable that some of this reduction could be attributed to afferent feedback from the foot. Similarly, load related afferent feedback is also considered to be an important mechanism that can influence the pattern of muscle activity during walking [5]. It is therefore conceivable that during stance the changing pressure distribution on the foot sole could provide feedback relevant to events during the gait cycle. In this study we applied tonic pressure to the skin overlying the metatarsal area of the foot sole. During gait the forces acting on this region of the foot will be greatest prior to the initiation of swing (toe off) and under these conditions it is conceivable that inhibitory actions onto plantar flexor muscles could contribute to the timing of the transition from stance to swing as suggested by Abbuzzese et al. [1]. Abnormally large variability in step-cycle duration is reported in patients with sensory polyneuropathy of the feet [10] and the gait impairment of these subjects has been related to the loss of reflex activity mediated by low threshold cutaneous afferents. Similarly, it has been stated that electrical stimulation of the foot sole prior to swing reduces the effort of walking in ambulatory SCI patients by improving swing as a result of a reduction in limb stiffness [4]. The demonstration that pressure applied directly to the foot sole in normal subjects and complete SCI subjects during sitting can powerfully inhibit the soleus H-reflex supports the hypothesis that feedback from load sensitive receptors in the foot sole may contribute to the regulation of the human step cycle. The adequate stimulation of these afferents may therefore be useful not only in relation to locomotor training in SCI subjects but could also be helpful in the management of reflex induced extensor hypertonicity.

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