Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2015;96:750-3

BRIEF REPORT

Cortical Activation During Visual Illusory Walking in Persons With Spinal Cord Injury: A Pilot Study

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Abstract

Objective: To determine the location of cortical activation during a visual illusion walking paradigm, a recently proposed treatment for spinal cord injury (SCI)−related neuropathic pain, in persons with SCI compared with able-bodied controls.

Design: Pilot experimental functional magnetic resonance imaging (fMRI) trial.

Setting: Outpatient rehabilitation clinic.

Participants: Persons with paraplegia (n=3) and able-bodied participants (n=5) were included in this study.

Interventions: Not applicable.

Main Outcome Measure: Cortical activation as measured by the blood oxygenation level-dependent method of fMRI.

Results: During visually illusory walking there was significant activation in the somatosensory cortex among those with SCI. In contrast, able-bodied participants showed little to no significant activation in this area, but they showed activation in the frontal and premotor areas.

Conclusions: Treatment modalities for SCI-related neuropathic pain that are based on sensory input paradigms (eg, virtual walking, visual illusory walking) may work by targeting the somatosensory cortex, an area that has been previously found to functionally reorganize after SCI.

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Approximately 70% of persons report pain after spinal cord injury (SCI).[1] Neuropathic pain is one form of post-SCI pain that is experienced in a region of sensory disturbance around or below the zone of injury. SCI-related neuropathic pain is often refractory, with many individuals experiencing only modest to minimal responsiveness to currently available treatments.[2] It is for this reason that novel treatment approaches to address SCI-related neuropathic pain are now being explored with promising initial results.

Novel treatments for SCI-related neuropathic pain are based on the assumption that cortical activity is continuously modulated by afferent, intersensory processes.[3] When disruptions in this cortical-afferent operating feedback system occur (eg, in amputation), the brain can functionally reorganize, a phenomenon thought to underlie the pain that is experienced.[4] Reinstating sensory input via visual illusion (eg, mirror box therapy for phantom limb pain) has been found to promote pain relief[5,6]; moreover, some sensory input paradigms have been shown to reverse the reorganization thought to underlie phantom pain.[7] Similarly, functional cortical reorganization in the somatosensory cortex has been linked to SCI and to a greater degree of pain among those with SCI-related pain.[8] Additionally, existing evidence suggests that when persons with SCI-related neuropathic pain are provided the visual illusion that they are walking, the severity of their pain is reduced.[9,10]

If in fact SCI-related neuropathic pain is alleviated by reinstating sensory input through visual illusion walking paradigms, then it remains to be understood how these treatments affect the cortical correlates of SCI-related neuropathic pain and how they perhaps reverse maladaptive functional reorganization. It has been shown that mirror box therapy results in sensorimotor activation contralateral to the virtual hand, supporting the theory that perception plays a large role in sensorimotor cortical activity.[11] Providing the visual illusion of walking may have a similar effect to mirror box therapy; however, the cortical region of

Presented to the Association of Academic Physiatrists, March 6−10, 2013, New Orleans, LA; and the Academy of Spinal Cord Injury Professionals, September 1-3, 2014, St Louis, MO.

Supported by the Rehabilitation Research Experience for Medical Students Program of the Association of Academic Physiatrists; National Institute on Disability and Rehabilitation Research (grant no. H133N110008); and National Institutes of Health (grant no. 1 K23 HD073680-01A1).

Disclosures: none.

0003-9993/14/$36 - see front matter © 2015 by the American Congress of Rehabilitation Medicine

http://dx.doi.org/10.1016/j.apmr.2014.10.020

Table 1 Age and injury characteristics of participants

Participants	Age (y)	Years Since Injury	Level of Injury	ASIA Impairment Scale Grade*
SCI	32	6.9	T3	A
	25	1.0	T10	C
	30	0.8	T10	A
Control	31.6±7.8†	NA	NA	NA

Abbreviation: NA, not applicable.
* Grade A refers to complete injuries, and grades B through D refer to incomplete injuries.
† Value is mean ± SD.

activation has not been characterized. Therefore, the aim of this study was to determine the location of cortical activation during a visual illusory walking paradigm in persons with SCI compared with able-bodied controls. We hypothesized that the visual illusion of walking would activate the sensorimotor cortex in persons with SCI and that the patterns of activation would be different than that of able-bodied participants.

Methods

Participants

Three persons with SCI (2 men, 1 woman) who were non-ambulatory, manual wheelchair users were recruited from an outpatient rehabilitation center (table 1). Additionally, data from 5 able-bodied controls (2 men, 3 women) were used for comparison. The study was approved by the institution's review board, and informed written consent was obtained from all participants for all of the procedures.

Magnetic resonance imaging scanning and image processing

Whole-brain images were acquired using a Philips Achieva 3T MRI system,[a] and the blood oxygenation level-dependent method of functional magnetic resonance imaging (fMRI) was used to measure change in cerebral blood flow during presentation of each stimulus. A block design was used such that participants viewed separate 30-second blocks of the fixation point (resting state), visual illusion of walking, and visual illusion of wheelchair use. The stimuli were projected to each participant on a magnetic resonance imaging–compatible screen while lying on the scanner. The sequence of stimuli was repeated 4 times for a total of 8 minutes.

Visual illusory walking

The visual illusory walking paradigm was adapted from an ongoing, larger study examining the effects of an immersive, simulated walking experience presented in a 3-dimensional video to participants. Because of the constraints of magnetic resonance scanning and the necessity to have demagnetized video display equipment, the walking stimuli could only be presented in a 2-dimensional format during scanning. The walking stimuli consisted of a video of an actor, in first person view, walking along a path. The control stimuli consisted of the same actor, in first person view, propelling a manual wheelchair along the same path for the same length of time (fig 1). Prior to the presentation of the stimuli during scanning, participants were instructed to imagine that they themselves were performing the movements of the actor, but without actual movement of limbs. They were instructed to gaze at a fixation point during resting state scanning.

After scanning, participants were asked to rate how immersive/realistic the fMRI-adapted virtual scenes were on a 5-point Likert scale (1 = not at all, 2 = slightly, 3 = moderately, 4 = very much so, 5 = extremely). Participants were also asked to rate, using the same scale, how adequately they were able to imagine that they were performing the movements.

List of abbreviations:

fMRI **functional magnetic resonance imaging**
SCI **spinal cord injury**

Fig 1 Still-frames of first person walking (*top*) and wheeling (*bottom*) conditions.

Analysis

The fMRI images were processed using SPM8 software,[12,b] correcting for motion artifact, normalized to the Montreal Neurological Institute template, and smoothed using a 8-mm full-width half-maximum Gaussian filter. Using general linear modeling, a contrast was modeled between the walk and wheel conditions; therefore, significant activations ($P<.01$) during the illusory walking condition, above and beyond that of the illusory wheeling condition, could be observed. Differences in the average signal intensity during walking, while controlling for wheeling, were then determined for each group.

Results

When the pattern of activation in the contrast (cortical activation during the walking condition minus the wheeling condition) was examined, differences emerged. Among persons with SCI, there