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Augmented multisensory feedback enhances locomotor adaptation in humans with incomplete spinal cord injury

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Different forms of augmented feedback may engage different motor learning pathways, but it is unclear how these pathways interact with each other, especially in patients with incomplete spinal cord injury (SCI). The purpose of this study was to test whether augmented multisensory feedback could enhance aftereffects following short term locomotor training (i.e., adaptation) in patients with incomplete SCI. A total of 10 subjects with incomplete SCI were recruited to perform locomotor adaptation. Three types of augmented feedback were provided during the adaptation: (a) computerized visual cues showing the actual and target stride length (augmented visual feedback); (b) a swing resistance applied to the leg (augmented proprioceptive feedback); (c) a combination of the visual cues and resistance (augmented multisensory feedback). The results showed that subjects' stride length increased in all conditions following the adaptation, but the increase was greater and retained longer in the multisensory feedback condition. The multisensory feedback provided in this study may engage both explicit and implicit learning pathways during the adaptation and in turn enhance the aftereffect. The results implied that multisensory feedback may be used as an adjunctive approach to enhance gait recovery in humans with SCI.

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1. Introduction

One of the most common goals of rehabilitation in patients with incomplete spinal cord injury (SCI) is to regain functional walking (Anderson, 2004), as limitations in mobility can adversely affect most activities of daily living (Noreau, Fougeyrollas, Post, & Asano, 2005; Post & Noreau, 2005). Afferent inputs play an important role in gait training, as they have the potential to facilitate neuroplasticity associated with improved walking following a spinal lesion (Barbeau, Fung, Leroux, & Ladouceur, 2002). Patients with an incomplete SCI usually experience impaired afferent inputs due to damage of the sensory ascending pathways. As a result, enhancing afferent inputs may be crucial in gait rehabilitation for patients with an incomplete SCI.

Providing augmented feedback is one approach to enhance afferent inputs. Augmented feedback can be provided through different sensory channels. Adding a swing resistance to the leg during walking is one way to augment proprioception, as the resistance stimulates proprioceptors such as muscle spindles and Golgi tendon organ and creates error signals through the proprioceptive pathways (Lam & Pearson, 2001). Studies on patients with incomplete SCI have shown that swing resistance can enhance the output of the leg flexors and induce an aftereffect consisting of an increase in step/stride length following load release (Houldin, Luttin, & Lam, 2011; Lam, Wirz, Lünenburger, & Dietz, 2008; Yen, Schmit, Landry, Roth, & Wu, 2012). The occurrence of aftereffect has been thought of as an indicator that central command has been updated (Blanchette & Bouyer, 2009) and is a phenomenon compatible to motor learning (Fortin, Blanchette, McFadyen, & Bouyer, 2009). In fact, the force perturbation paradigm has been regarded as implicit learning as the patients learned to take longer strides without a conscious decision to do so (Patton & Mussa-Ivaldi, 2004).

On the other hand, augmented visual feedback is a commonly used approach to help patients with incomplete SCI detect stepping errors. For example, clinicians usually place visual cues on the floor to help patients recognize the difference between the expected and actual stride lengths (Amatachaya, Keawsutthi, Amatachaya, & Manimmanakorn, 2009). According to the visual goal, patients modify their motor plan to minimize errors. This process requires the engagement of cognitive process (i.e., a conscious decision is made by the patient to take a longer step), and is regarded as explicit learning.

While the swing resistance and augmented visual feedback may induce different motor learning processes, both of them may modulate the patients' stride/step length through similar pathways, including: (a) modification of motor commands for stepping at the supraspinal level; (b) enhancement of neural descending drive in the residual spinal pathways. Specifically, error signals detected by the visual and proprioceptive channels can induce motor adaption, causing recalibration of motor command for stepping to minimize the different between the actual and expected stride/step length (Bastian, 2008). The neural descending drive appears to increase when one moves against resistance (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Sale, 1988). Providing augmented visual feedback during gait training can enhance active involvement and thus increase descending drive and motor outputs (Banz, Bolliger, Colombo, Dietz, & Lunenburger, 2008). This leads us to postulate that providing the swing resistance and augmented feedback together (multisensory feedback) may enhance gait training outcomes compared to providing either type of feedback alone (unisensory feedback) in patients with incomplete SCI. Specifically, multisensory feedback may further augment neural descending drive in the residual spinal pathways. Also, error-driven learning may be more effective (i.e., effects can retain longer) when different learning pathways (implicit and explicit) are simultaneously engaged.

However, literature is contradictory on the effect of combining implicit and explicit learning on motor training outcomes. While some investigators reported beneficial effects of explicit information on implicit motor learning (Boyd & Winstein, 2001; Curran & Keele, 1993), others reported detrimental effects (Green & Flowers, 1991; Malone & Bastian, 2010; Reber, 1976) or modest consequences (Reber & Squire, 1998; Shea, Wulf, Whitacre, & Park, 2001). These contradictory findings may result from some combined factors such as task difference, the type, timing, and salience of explicit information, and the characteristics of participants (Boyd & Winstein, 2004). In particular, we are not aware of any studies investigating the impact of explicit information on implicit motor learning in patients with SCI during locomotion.