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Research report

Peripheral electrical stimulation increases corticomotor excitability and enhances the rate of visuomotor adaptation

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HIGHLIGHTS

- Rate of visuomotor adaptation is enhanced following 20 min of motor PES compared to sham PES.
- Decreasing corticomotor excitability with PES prior to a visuomotor task did not impact adaptation performance.
- Visuomotor adaptation performance overall was similar across PES interventions.

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ABSTRACT

Peripheral electrical stimulation (PES) modulates corticomotor excitability but its effect on motor performance has not been thoroughly investigated. The purpose of this study was to assess whether increases and/or decreases in corticomotor excitability, induced by PES, influenced motor performance using a visuomotor adaptation task. Three PES interventions (motor stimulation, sensory stimulation or sham) were delivered to the first dorsal interosseous (FDI) in 30 healthy participants matched for age, gender and handedness. Motor stimulation was applied to increase corticomotor excitability, sensory stimulation to decrease corticomotor excitability, while sham stimulation acted as a control. Corticomotor excitability was assessed using the amplitude of motor evoked potentials to transcranial magnetic stimulation recorded from FDI before and after each intervention. Following PES, participants completed a visuomotor adaptation task. This required participants to move a cursor accurately towards virtual targets with index finger movements when the cursor trajectory was rotated 30° counter clockwise. Performance was assessed as angular error (a measure of movement accuracy) and reaction time. The rate of visuomotor adaptation was greater following motor PES compared to sham, but not sensory, with no difference observed between sensory and sham. However, visuomotor adaptation performance overall (the total change in performance from beginning to end) was similar across intervention groups. These findings suggest that motor PES applied prior to task acquisition can facilitate the speed of adaptation.

1. Introduction

Neuromodulatory techniques that can alter corticomotor excitability to promote motor performance present novel opportunities for the management of neurological and musculoskeletal conditions [1,2]. Peripheral electrical stimulation (PES) is a widely available therapeutic technique [3]. Reviews have demonstrated that increases or decreases in corticomotor excitability occur following application of PES and are related to the frequency and intensity of stimulation [4,5]. Specifically, PES at motor intensities increases corticomotor excitability [6–8], whereas PES at sensory intensities decreases excitability [9–11]. Thus, PES may be a useful tool to facilitate movement and function in clinical settings. However, the relationship between PES-induced increases or decreases in corticomotor excitability and motor performance has not been thoroughly investigated.

Changes in corticomotor excitability are known to occur during motor tasks, and functional recovery following injury [12,13]. For example, acquiring a motor skill or practicing a motor task is associated with increased excitability in the corticomotor projec-

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tions to involved muscles [14–16]. In contrast, a non-skill or passive motor training does not alter corticomotor excitability [17–19]. In neurological populations such as stroke, decreased corticomotor excitability has been correlated with poorer clinical outcomes [20], whereas greater corticomotor excitability has been positively correlated with improved motor recovery [21,22]. These findings suggest that corticomotor excitability is an important physiological mechanism underpinning motor performance and functional restoration.

Based on these observations, there is the possibility that PES paradigms could be applied purposefully to induce changes in corticomotor excitability to enhance motor performance and function in a range of pathologies. However, only one study has investigated the effect of PES on corticomotor excitability and motor task performance. McDonnell and Ridding [7] reported that PES-induced increases in corticomotor excitability facilitated the performance of a grooved pegboard task (GPT) in healthy individuals. However, measuring performance with the GPT provides information about manual dexterity rather than specific characteristics of motor learning (e.g. reaction time and movement accuracy). Thus, it is unknown if reaction time and movement accuracy are altered following PES-induced changes in corticomotor excitability. Here, we investigated the effect of PES-induced increases and decreases in corticomotor excitability on visuomotor adaptation. Visuomotor adaptation paradigms have been used extensively to investigate adaptation, a form of learning characterised by gradual improvements in performance in response to altered conditions [23]. Consistent with findings from other neuromodulation techniques [24,25], it was hypothesised that compared to sham stimulation, PES-induced increases in corticomotor excitability would enhance visuomotor adaptation, while PES-induced decreases in corticomotor excitability would impair adaptation.

2. Methods

2.1. Participants

Thirty healthy individuals (mean and standard deviation [SD] 22 ± 3 years; 15 females) were recruited for the study. All participants were right handed, verified by the Edinburgh Handedness Inventory [26]. Participants had no neurological or upper-limb conditions and completed a transcranial magnetic stimulation (TMS) safety-screening questionnaire prior to enrolment [27]. All participants provided written, informed consent in accordance with the Declaration of Helsinki. The Western Sydney University Human Research Ethics Committee approved the study.

2.2. Experimental protocol

Each participant was allocated to one of three PES interventions: motor stimulation, sensory stimulation or sham stimulation. Motor stimulation mimicked a voluntary contraction and was used to increase corticomotor excitability [4,28]. Sensory stimulation activated sensory nerves without eliciting a muscle response and was applied to decrease corticomotor excitability [10,11]. Sham stimulation acted as a control, whereby the machine was turned on but the intensity was set to zero without the participants knowledge [29]. The stimulation was applied to the first dorsal interosseous (FDI) muscle of each participant's right hand immediately following neurophysiological testing and familiarisation with a visuomotor rotation task (Fig. 1). Neurophysiological testing included measures of motor evoked potentials (MEPs) and muscle compound action potentials (M-waves) to FDI. These measures were taken before and after the PES intervention to assess the immediate effect of PES on corticomotor excitability. The visuomotor rotation task examined the effect of PES induced increases and decreases in corticomotor excitability on visuomotor adaptation.

2.3. Electromyography (EMG)

Electromyography was recorded with self-adhesive silver/silver chloride surface electrodes placed over the right FDI muscle belly. The reference electrode was placed over the right olecranon. The skin under the electrodes was lightly abraded using Nuprep skin prep gel (Weaver and Company, Colorado, USA) and cleaned with an alcohol wipe. Electromyographic signals were pre-amplified 1000 times, band pass filtered between 20 and 1000 Hz, and sampled at 2 kHz using Signal 3 software and Power 1401 data acquisition system (Cambridge Electronic Design, Cambridge, UK).

2.4. Transcranial magnetic stimulation

Transcranial magnetic stimulation (TMS) was applied to the left primary motor cortex using a Magstim 200 stimulator (Magstim Co. Ltd., Dyfed, Uk) with a figure-of-eight coil (7 cm in diameter). The coil was positioned at 45° to the sagittal plane with the handle posterior. This coil orientation preferentially induces current in a posterior-to-anterior direction and is optimal for the stimulation of the hand region of the motor cortex. The optimal scalp site for evoking an MEP in FDI of the right hand was then determined as the coil position that evoked the maximal peak-to-peak MEP response [30]. Once the optimal site was determined, the position of the coil was marked on the scalp with a felt tip marker to enable reliable coil placement for repeated measures [31]. Stimulation intensity was determined by calculating the resting motor threshold (RMT). The RMT was defined as the minimum intensity at which five out of 10 stimuli applied at the optimal site evoked peak-peak amplitudes of at least 50 μV in FDI [30]. This intensity was used to record 30 MEPs before and after each PES intervention. All TMS procedures adhered to the TMS checklist of methodological quality [32].

2.5. Median nerve stimulation

Muscle compound action potentials (M-waves) were elicited using a constant current stimulator (Ds7A, Digitimer Ltd., Welwyn Garden City, UK) to control for excitability changes occurring at the muscle and neuromuscular junction in response to PES [33]. Single maximum currents (100 μV pulse duration) were delivered to the right ulna nerve via bipolar surface electrodes. Stimulus intensity was set 150% above that required to elicit a maximal muscle compound action potential (M_{max}) in the right FDI muscle at rest. 5 M-waves were recorded before and after each PES intervention.

2.6. PES interventions

A four-channel TENS/EMS combo machine (Medihightec Medical Co. Ltd., Keelung City, Taiwan) was used to deliver the three PES interventions to the right FDI muscle belly. Each intervention lasted for 20 min and was delivered through the EMG electrodes. All stimulations used an asymmetrical rectangular biphasic waveform with a pulse duration of 0.1 ms. Habituation to the stimulus was monitored and, where necessary, the intensity of stimulation was adjusted to maintain a constant response. To control for attention, participants were given verbal reminders to focus on their stimulated hand every 5 min [34]. Each intervention is described in detail below.

1. Motor Stimulation: The parameters of motor stimulation were set to mimic a voluntary contraction in the FDI muscle. The electrical current was delivered at 30 Hz and ramped at a rate of six surges per minute (4 s on, and 6 s off). Intensity was increased