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Motor transfer from the corticospinal to the corticobulbar pathway

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ABSTRACT

There are multiple descending neural pathways, including the corticospinal pathway (CS) and the corticobulbar pathway (CB). The corticospinal pathway has been shown to exhibit within-pathway (CS-to-CS) motor transfer. However, motor transfer across each pathway (CS-to-CB or CB-to-CS) has yet to be studied in depth. The aim of the present study was to examine the effects of cross-pathway motor transfer between the ankle (CS) and tongue (CB) after training with a ballistic goal-directed motor task. Twelve healthy participants were recruited for this two-day experimental study. Six participants performed a ballistic goal-directed task with their ankle on Day 1 (ankle dorsiflexion), then tongue on Day 2 (elevate tongue against IOPI). The other 6 participants performed the same task with their tongue on Day 1, then ankle on Day 2. Both the ankle and tongue tasks (50 trials each) required matching force and time to a visual target. Our findings indicate that participants who underwent ankle training on Day 1 exhibited decreased tongue force error on Day 2 compared with participants who completed the tongue training on Day 1, with no prior ankle training ($p = 0.02$) (i.e. greater accuracy). This finding suggests that cross-pathway transfer from the corticospinal pathway to the corticobulbar pathway occurred with respect to force error. In other words, training of the ankle (CS) translated to improved training performance of the tongue (CB) through a reduction in force error. However, the reverse was not true – training the tongue did not elicit improved performance of the ankle. Nonetheless, if training with the corticospinal pathway can lead to improved corticobulbar pathway functioning, incorporating multi-pathway rehabilitation techniques might be valuable for clinicians across medical disciplines.

1. Introduction

The field of rehabilitation aims to improve patients' motor learning in order to regain motor function [5,6,8,11]. There are multiple neural pathways that regulate motor control of the human body, two of which include the corticospinal pathway (CS), and the corticobulbar pathway (CB) [12]. Prior studies demonstrate that the corticospinal pathway exhibits within-pathway (CS-to-CS) motor learning [13,18,21]. However, motor learning across the corticospinal pathway and the corticobulbar pathway has yet to be studied in depth. Therefore, this study aimed to further explore cross-pathway motor learning between the ankle (CS) and tongue (CB) after practice of a goal-directed task.

The corticospinal pathway and corticobulbar pathway are two of the descending neural pathways that regulate voluntary control of muscles [12]. The corticospinal pathway controls movements of the limbs and is therefore involved in tasks such as grasping, walking, and reaching [7,16]. The corticobulbar pathway controls movements of the head and neck and is therefore involved in tasks such as speaking and swallowing [22]. The corticospinal pathway and corticobulbar pathway interact during everyday activities such as self-feeding, walking while talking, or playing an instrument while singing. As such, it is clear that these pathways collaborate with one another, yet, it remains unclear whether practicing a task with one pathway influences the functioning of the other.

Motor learning requires practice of a motor task [20]. Through practice, neural connections in the brain become more permanent which allows the individual to extract and acquire important information about the task. Once task information has been extracted and acquired, that information is stored and can be used to execute similar tasks [24]. In this study, we assessed motor learning with transfer tasks. Transfer tasks examine the extent to which a previously learned skill influences the ability to learn a novel skill [9,19]. It is well known that transfer within the corticospinal pathway occurs [3,13,18,21]. For example, practice with ankle dorsiflexion improved performance of elbow

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flexion during a goal-directed task [3]. Recent research has suggested that when performing similar tasks (ankle dorsiflexion and tongue elevation tracking tasks), the corticospinal pathway integrates visual feedback superiorly to the corticobulbar pathway, enhancing motor learning and motor performance [15]. However, to our knowledge, the existence of cross-pathway transfer between the corticospinal pathway and the corticobulbar pathway (i.e. CS-to-CB; or CB-to-CS) has yet to be explored.

Exploring whether cross-pathway transfer between the corticospinal pathway and corticobulbar pathway exists could improve current rehabilitation approaches. Currently, deficits within the corticospinal pathway and the corticobulbar pathway are rehabilitated independently. For example, stroke rehabilitation of the upper and lower limbs directly targets the corticospinal pathway through electrical stimulation, sensory and strength training, as well as stretching of the affected limb [4,17]. Meanwhile, treatments for impaired swallowing directly target the corticobulbar pathway through dietary modifications, compensatory maneuvers, and lingual strength training [14]. However, if cross-pathway transfer exists then an individual could practice with one pathway (e.g. the healthier pathway) and improve the functioning of the other. In which case, individuals who have corticospinal impairments (i.e. paralysis/hemiparesis resulting from occlusion of the anterior cerebral artery or posterior cerebral artery) could utilize the corticobulbar pathway to improve motor functioning of the corticospinal pathway, whereas individuals who have corticobulbar impairments (i.e. dysarthria, dysphagia) could utilize the corticospinal pathway to improve motor functioning of the corticobulbar pathway. It is important to note that this form of multi-pathway rehabilitation does not preclude targeting the impaired pathway directly. Rather, we envision this form of rehabilitation to serve as a valuable addition to direct intervention, or as precursor to direct intervention when the impaired pathway is too weakened to target directly.

This study, therefore, aims to examine the phenomenon of cross-pathway transfer between the corticospinal pathway and the corticobulbar pathway. Specifically, we asked healthy participants to practice a goal-directed task with either their ankle or tongue and explored ankle (CS) performance after practice with the tongue (CB) and vice versa. We hypothesize that cross-pathway transfer will occur because the central nervous system, after practice, has the capacity to extract task relevant information and use it for analogous tasks (i.e. generalization) regardless of which pathway originally practiced the movement.

2. Methods

2.1. Participants

Twelve participants (19.5 ± 2.06 yrs; 6 males) volunteered to participate in this study. All participants reported being healthy without any known neurological impairment. The Institutional Review Board at the local university approved the procedures of this study. All participants signed a written informed consent prior to participation.

2.2. Experimental approach

Participants were evenly and randomly divided into two groups: Ankle-Tongue and Tongue-Ankle. Both groups performed two experimental sessions that were 24 h apart. The Ankle-Tongue group practiced goal-directed contractions with their ankle on Day 1, and with their tongue on Day 2. The Tongue-Ankle group practiced in the reverse order. See Fig. 1A. The procedures of both days were as follows: 1) three to five trials of a maximum voluntary contraction (MVC) task with ankle dorsiflexion or tongue contraction; 2) Familiarization to the task by practicing two to three trials of the goal-directed contraction at a different target than the actual target, and; 3) 50 trials of the goal-directed task with either the ankle or tongue.

2.3. Experimental set-up and apparatus

Participants were seated comfortably in an upright position and faced a 32-in. monitor (SyncMaster 275t+, Samsung Electronics America) that was located at eye level 1.25 m away. The monitor was used to display the visual feedback of the MVC and the goal-directed tasks. This visual biofeedback was derived via a custom written program in MATLAB (MathWorks, Natick, MA). All participants confirmed that they could see the display clearly.

For the ankle task the participant's position was as follows: the left hip joint was flexed to ~90° with 10° abduction, and the knee was flexed to ~90°. The left foot rested on a customized foot device with an adjustable footplate and was secured by straps over the metatarsals to ensure a secure position. This arrangement allowed only dorsiflexion of the ankle. See Fig. 1B. For the tongue task, participants were given a disposable, standard sized tongue bulb (IOPI Medical LLC) and were instructed to place the bulb comfortably in the mouth behind the alveolar ridge. Upon placement, the stem of the bulb was taped to the participant's chin in order to secure and maintain the bulb's position. The tongue bulb was attached to a tube (Medex, MX451FL) that connected to the Iowa Oral Performance Instrument (IOPI). The IOPI is used to measure tongue strength [1]. Participants were additionally given a small diameter tube and instructed to place the tube inside the mouth and allow it to rest between the participant's inner left cheek and teeth. This tube was then attached to a 50cc syringe filled with water. See Fig. 1C. The maximum voluntary force exerted during ankle dorsiflexion was measured with a force transducer (Miniature Beam Load Cell, Interface Inc., AZ, USA) that was located parallel to force direction on the customized foot device. The ankle force signal was sampled at 1000 Hz with a Power 1401 A/D board (Cambridge Electronic Design, Cambridge, UK). The tongue force signal was measured with the IOPI and sampled at 1000 Hz with a Power 1401 A/D board. Signals for both the ankle and tongue were stored on a personal computer with a NI-DAQ card (Model USB6251, National Instruments, Austin, TX).

2.4. MVC task

The maximum voluntary contraction force of both the ankle and tongue were measured prior to performing the goal-directed tasks. Participants were instructed to exert and release their maximum force. Participants performed the MVC task 3–5 times in order to ensure that each measurement was within 5% of each other. The average MVC value was then calculated. See Table 1. The average MVC value was obtained in order to calculate 15% of each participant's MVC, which later served as the target force for the goal-directed task. At the end of each session MVC tasks were repeated to gauge whether the experiment induced any muscle fatigue.

2.5. Goal directed task

Participants performed 50 isometric contractions with either the ankle or tongue that required them to accurately match a force and time target. The targeted force was 15% of their respective MVC (an appropriate value to prevent the participant from becoming fatigued after multiple repetitions of the task) and the targeted time to peak force was 180 ms. The task was divided into three phases: (1) GET READY; (2) CONTRACT; and (3) FEEDBACK. See Fig. 2. The GET READY phase began with the presence of a red target on the monitor for 2 s. This was a cue for the participants to prepare for the CONTRACT phase. The CONTRACT phase began when the red target became green. This change in color was a cue for participants to perform the goal-directed contraction. The green target remained visible on the monitor for 3 s and participants were instructed to initiate the contraction at their convenience (not a reaction time task). The recording of the task began when participants initiated their contraction. No visual feedback was provided during the CONTRACT phase. The FEEDBACK phase began at