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Full Length Article

Integration of visual feedback and motor learning: Corticospinal vs. corticobulbar pathway

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ABSTRACT

Although movement is controlled by different descending pathways, it remains unknown whether the integration of visual feedback and motor learning differs for movements controlled by different descending pathways. Here, we compare motor control and learning of the ankle joint and tongue because they are primarily controlled by the corticospinal and corticobulbar pathways, respectively. Twelve young adults (19.63 ± 2.11 years, 6 females) practiced a tracking task (combination of 0.02, 0.37, 0.5, and 1 Hz) with ankle dorsiflexion and with tongue elevation for 100 trials. The participants practiced each effector (ankle and tongue) in different days and the order of the effector was counterbalanced. Following practice, participants performed the same tracking task with concurrent contractions of the tongue and ankle (dual tracking task; transfer) with three different visual feedback conditions (no visual feedback, visual feedback only for ankle, visual feedback only for tongue). We quantified the force accuracy (RMSE) from each effector during the practice and transfer periods. During practice, the force accuracy and performance improvement to the visuomotor task was greater for the ankle dorsiflexion than tongue elevation. During the transfer task, the ankle dorsiflexion was more accurate than tongue elevation, independent of whether visual feedback was given for the ankle or tongue. The greater performance improvement for the ankle dorsiflexion during practice was related to superior transfer performance. These findings suggest that the corticospinal pathway integrates visual feedback more efficiently than the corticobulbar pathway, which enhances performance and learning of visuomotor tasks.

1. Introduction

Visual feedback during practice is important for motor learning (Franklin, Wolpert, & Franklin, 2012; Sigrist, Rauter, Riener, & Wolf, 2013). For example, the ability to generalize a practiced motor task (transfer) is better for individuals who received visual feedback during practice than for those who did not (Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997). Although visual feedback during practice enhances motor learning, it remains unknown whether it is similar for effectors that are controlled by different descending pathways. In this paper, we compare motor learning of the ankle joint and tongue because they are primarily controlled by the corticospinal and corticobulbar pathways, respectively. In this context, we operationally define motor learning as the ability of the participants to transfer performance after practice.

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Visual feedback is necessary to detect errors in performance relative to the target. These errors serve as information to revise the motor plan and improve performance of subsequent trials (Chen, Kwon, Fox, & Christou, 2014; Gordon & Ghez, 1987). Visual feedback is critical when learning a novel visuomotor task (Melendez-Calderon, Masia, Gassert, Sandini, & Burdet, 2011), which requires voluntary visuomotor corrections (D. W. Franklin & Wolpert, 2008; Lee, Moseley, & Refshauge, 1990; Saunders & Knill, 2003; Snodgrass, Rivett, Robertson, & Stojanovski, 2010; Swinnen et al., 1997). For example, retention and transfer of the practiced task is superior for individuals who received visual feedback during practice than those who did not (Snodgrass et al., 2010; Swinnen et al., 1997). Therefore, the use of visual feedback is a critical factor for motor learning.

Different descending pathways are involved in the voluntary control of muscles (Lemon, 2008). For example, the corticospinal and corticobulbar pathways belong to the pyramidal tracts and are responsible for the voluntary control of the body and face muscles, respectively (He, Dum, & Strick, 1993; Morecraft, Louie, Herrick, & Stilwell-Morecraft, 2001). The corticospinal pathway appears to have an advantage for visually guided movements compared to the corticobulbar pathway because the limbs can be visually observed and this visual observation is incorporated throughout life to create successful limb movements. Furthermore, evidence suggests that there is an interaction between visual feedback and descending pathways for effective motor control (Honki et al., 2016; Kennedy & Christou, 2011; Patla, 1997). For example, for the corticospinal pathway (assessed with ankle dorsiflexion), control of force is superior with visual feedback than without visual feedback (Kennedy & Christou, 2011). In contrast, mixed outcomes exist for the corticobulbar pathway. Assessed with tongue elevation, control of force was similar with or without visual feedback (Honki et al., 2016). However, skill learning of intricate laryngeal swallowing movements improve significantly with visual feedback (Azola, Sunday, & Humbert, 2017). Thus, these findings suggest that the corticospinal pathway integrates visual feedback more efficiently than the corticobulbar pathway. However, this conclusion is indirect as the findings that compare the two pathways come from different studies.

In this study, we directly compare the visuomotor control of the corticospinal (assessed with ankle dorsiflexion) and corticobulbar (assessed with tongue elevation) pathway to determine whether the integration of visual feedback and motor learning differ for the two pathways. We hypothesized that the corticospinal pathway will more efficiently integrate visual feedback than the corticobulbar pathway, which will be beneficial to motor learning.

2. Materials and methods

2.1. Participants

Twelve young adults (19.63 ± 2.11 years, 6 females) volunteered to participate in this study. All participants were healthy, moderately active, and had normal or corrected vision. No participant reported having speech or swallowing impairments. The Institutional Review Board at the University of Florida approved the procedures of this project and participants read and signed an informed consent prior to the experiment.

2.2. Experimental protocol

Fig. 1A describes our experimental protocol. We randomly assigned participants into a tongue-ankle or an ankle-tongue practice group. All individuals participated in two experimental sessions. For the tongue-ankle practice group, participants practiced the tracking task with tongue elevation in the first session and 24 h later they practiced the tracking task with ankle dorsiflexion. For the ankle-tongue practice group, the order of practice was reversed. Practice of the tracking task consisted of 50 trials with a target and visual feedback about their force output (Fig. 1B) followed by 50 trials with visual feedback about their force output but no target feedback. In the second session, following practice, participants performed the same tracking task with concurrent contractions of the tongue and ankle (dual tracking task; transfer) with three different visual feedback conditions: 1) 10 trials with no visual feedback (no force output or target), 2) 10 trials with target and visual feedback only for ankle, and 3) 10 trials with target and visual feedback only for tongue.

Each session lasted ~2 h. At the beginning of each session, we explained the experimental procedures and the tracking task (tongue elevation or ankle dorsiflexion) to the participants. Each participant performed the following procedures within a session: 1) maximal voluntary contraction (MVC) tasks with tongue elevation or ankle dorsiflexion; 2) practice of 3–5 tracking trials at a target different from the actual target; 3) the tracking task; 4) repetition of the MVC task. In the second session, each participant performed the same procedures explained above (1–4) and the dual tracking task (transfer). The dual tracking task consisted of the following: 1) 1–3 practice trials with target and visual feedback for both tongue and ankle; 2) 10 trials with no visual feedback (no target); 3) 10 trials with target and visual feedback only for ankle; 4) 10 trials with target and visual feedback only for tongue; 5) repetition of the MVC task.

2.3. Experimental arrangement

2.3.1. Experimental setup and apparatus

The participants were seated comfortably in an upright position and faced a 32-inch monitor (Sync Master™ 275t+, Samsung Electronics America, NJ, USA) located 1.25 m away at eye level. The monitor was used to display the force output produced by tongue elevation and ankle dorsiflexion and the target using a custom-written program in Matlab® (Math Works™ Inc., Natick, Massachusetts, USA). All participants affirmed that they could see the display clearly.