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Behavioural and neurophysiological disruption of corticobulbar motor systems and their effects on sequential pharyngeal swallowing

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HIGHLIGHTS

- Disrupting primary motor networks (M1) during a motor task can affect performance
- The role of primary motor networks in sequential swallowing is not fully understood
- Neither volitional nor reflexive sequential swallowing are affected by M1 disruption
- In contrast, purely volitional motor tasks such as finger tapping were affected
- Medullary pattern generators may play a greater role in sequential swallowing

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ABSTRACT

Primary motor networks are known to be involved in the control of voluntary oral movements as well as the modulation of pharyngeal movements during experimentally controlled single swallows performed on command. The role of these networks in the more typical task of sequential swallowing remains unexplored. This study evaluated the hypothesis that experimental disruption of motor cortical activation would reduce the rate and regularity of repeatedly performed volitional or volitionally initiated motor tasks controlled by corticospinal (finger tapping) and corticobulbar (eyebrow movement, jaw opening, volitional sequential swallowing) motor systems, but would not influence a more reflexive corticobulbar task (reflexive sequential swallowing to pharyngeal water infusion). This premise was investigated in 24 healthy participants using two techniques: a dual task paradigm and a transcranial magnetic stimulation paradigm. Disruption effects were quantified by changes in rate and regularity of performance for each tested motor task. In summary, volitional motor tasks controlled by corticospinal motor networks (finger tapping) are more susceptible to behavioural and neurophysiological disruption than tasks controlled by cortiobulbar motor networks containing a reflexive component (both volitional and experimentally initiated consecutive swallowing). Purely volitional motor tasks controlled by the corticobulbar motor system (eyebrow raising or jaw opening) were affected in similar ways as the volitional corticospinal motor tasks. In summary, tasks involving sequential pharyngeal swallowing - whether volitionally or experimentally initiated - are largely robust against disruption of primary cortical motor networks, supporting a key role of medullary CPGs in the motor control of sequential pharyngeal swallowing.

Abbreviations: CPGs, central pattern generators; DT, dual task; EDM, extensor digitorum muscle; FOM, floor of mouth; RM ANOVA, repeated measures analysis of variance; sEMG, surface electromyography; TMS, transcranial magnetic stimulation; UES, upper esophageal sphincter.

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1. Introduction

The primary motor cortex (M1) has been implicated in the neural control of human swallowing. Recent neuroimaging and clinical studies provide evidence that M1 is involved not only in the voluntary movements of the jaw and tongue during the oral phase of swallowing, but

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may also play a role in the patterned pharyngeal swallowing response historically thought to be driven by central pattern generators (CPGs) located in the medulla. For example, functional neuroimaging studies revealed multifocal cortical activation during swallowing, including the primary motor cortex, suggesting involvement of this area in swallowing motor control [1–3]. Recent evidence from studies employing neuro-modulatory stimulation of M1 suggests that changes in the excitability of corticobulbar motor networks can increase the accuracy of response [4,5] or shorten swallowing response times [6] on a swallowing reaction time task. In addition, cortical lesions involving M1, for example following stroke, can result in swallowing impairment. Specifically, patients presenting with a single cortical lesion affecting primary motor cortices can result in both oral and pharyngeal dysphagia [7]. Understanding the precise involvement of cortical motor networks in unimpaired swallowing may facilitate diagnostic and rehabilitative approaches in clinical swallowing rehabilitation.

The neural organization of motor networks involved in swallowing can be studied through behavioural and neurophysiologic disruption. Behavioural disruption can be achieved using a dual task (DT) [8]. In a DT paradigm, two discrete tasks are performed simultaneously and the degree of interference in central nervous system control is observed through behavioural changes in the performance of either of the simultaneously performed tasks [9]. A DT paradigm adopted to investigate the cortical lateralisation of swallowing motor control demonstrated that when paired with the left hemisphere task of silent word repetition, volume of bolus swallowed decreased significantly in unimpaired right handed individuals [10]. When swallowing was paired with bilateral finger-tapping, tapping rate significantly decreased, providing preliminary support for the notion that swallowing is bilaterally represented in the primary motor cortices. In a subsequent study, both a typically right hemispheric task (visuospatial line-orientation task) and a typically left hemispheric task (silent word repetition) interfered with simultaneously performed swallowing, as reflected by a decreased number of swallows and decreased average volume per swallow, respectively [11]. The results of these studies suggest that although swallowing motor control appears to be bilaterally represented, each hemisphere may play a distinct role.

An alternative means to explore the functional involvement of primary motor circuits in human swallowing motor control is to evaluate changes in motor function in response to temporary neurophysiological disruption of the involved motor system via transcranial magnetic stimulation (TMS) [12]. A period of trans-synaptic inhibition is observed as a relative quiescence in the ongoing electromyographic signal obtained from the activated target muscle following suprathreshold magnetic stimulation of that muscle's cortical motor representation [13]. This inhibition of neural output from descending cortical output neurons enables researchers to observe quantifiable functional changes in the performance of motor behaviours. For example, a suprathreshold magnetic stimulus applied during a reaction-time finger movement task can delay the onset of movement when given in the period between stimulus and movement onset [14]. Similarly, it has been demonstrated that 'virtual lesioning' of the pharyngeal motor representation on M1 using inhibitory repetitive TMS affects swallowing onset times in a swallowing reaction time paradigm [15].

Findings from these studies provide preliminary evidence that primary motor networks are involved in the control of voluntary oral movements and likely also influence the output of central pattern generators that orchestrate pharyngeal movements during swallowing. Most of previous research investigated effects on single swallows performed on command. The specific role of M1 in the everyday task of sequential swallowing, both volitionally and reflexively initiated, however, remains unexplored. As the biomechanics of single and sequential swallowing differ greatly, we sought to further elucidate the role of primary motor circuits in the control of sequential swallowing. For this, we undertook two experiments to evaluate the effects of behavioural (by means of a DT paradigm) and neurophysiological (by means of TMS) disruption of motor cortical activation on repeatedly performed motor tasks controlled by corticobulbar and corticospinal motor systems. Disruption effects on motor performance were quantified through changes in the rate and regularity with which each tested motor task was performed. We hypothesized that both disruption paradigms would reduce the rate and regularity of the volitional motor tasks but not the reflexive swallowing task.

2. Materials and methods

2.1. Subjects

This study was approved by the appropriate human research ethics committee. All volunteers provided written informed consent prior to participation and this study conformed to the standards set by the Declaration of Helsinki (2008). Twenty-four right-handed research participants (mean age 24.4, SD = 6.3, 12 females) attended a specialized swallowing research laboratory for two experimental sessions, performed in randomized order. In Experiment 1, we evaluated the influence of DT performance, whereas in Experiment 2 we evaluated the effects of single-pulse TMS applied over left or right primary motor cortices. In each session, each participant completed various research tasks, both under control conditions (without disruption) and under experimental conditions (with disruption). In Experiment 1, research tasks included non-swallowing tasks: (i) right finger tapping, (ii) left finger tapping, and (iii) rapid up and down eyebrow movement, as well as two swallowing tasks: (iv) volitional sequential swallowing of water through a straw and (v) reflexive sequential swallowing in response to direct injection of water into the pharynx. In Experiment 2, the same finger tapping and swallowing tasks were evaluated; instead of the eyebrow task, a rapid up and down jaw movement task was evaluated. The jaw movement task was evaluated because it shares peripheral muscles and innervation with reflexive swallowing, while being under purely voluntary control. The jaw movement task could not be included in Experiment 1 as it was not feasible to pair this task with the swallowing tasks. All tasks were performed in randomized order in each session.

2.2. Experimental procedures

2.2.1. Non-swallowing tasks

For the finger tapping tasks, a custom designed two-button (right, left), finger-tapping device was used (Department of Medical Physics and Bioengineering at Christchurch Public Hospital, Christchurch, New Zealand), which generated a single transistor-transistor logic trigger when a button press completed an electrical circuit. Each tap was recorded and represented as a binary marker on customised computer software. Participants were asked to tap the button for 7 s as rapidly and consistently as possible. This duration was chosen because preliminary pilot experiments indicated that an adequate number of consecutive swallows could be performed in this period without discomfort such as bloating, and consistency in duration between tasks was required for experimental control. The finger tapping task was completed for the left index finger and the right index finger independently with the number of finger taps for each hand identified offline for analysis.

To detect eyebrow movement (Experiment 1), surface electromyography (sEMG) electrodes (BRS-50 K, Blue SensorTM, Ambu, Denmark) were adhered to the skin overlying the right and left frontalis muscles. Reference electrodes were placed over the zygomatic bone bilaterally (2 cm lateral to the nose). Participants were asked to raise and lower their eyebrows as quickly and consistently as possible for 7 s.

For the rapid jaw movement measures (Experiment 2), sEMG electrodes (Tripletrode, Stens Corporation, California) were adhered to the skin overlying the masseter muscles (inter-electrode spacing of 22 mm), with the reference electrode placed laterally. Participants were asked to raise and lower their jaw as quickly and consistently as