



Research paper

Excitability of hand motor areas during articulation of syllables

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HIGHLIGHTS

- Increase in excitability of left-M1 hand area during articulation of syllables.
- The excitability did not increase during listening to syllables.
- Movement of the oral organs might be the key factor in increasing the excitability.

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ABSTRACT

It is known that articulating different syllables is linked to different grasp actions, e.g. [ti] is linked to precision grip, and [ka] to power grip. The aim of the present study was to test whether articulating or hearing these syllables would result in an increased activity in the representation of hand muscles involved in these two actions in a muscle-specific manner. To this end, we used transcranial magnetic stimulation (TMS) to investigate changes in the excitability of the left primary motor cortex (M1) innervating hand muscles while participants articulated or listened to meaningless syllables, listened to a metronome, or observed a fixation cross. The motor-evoked potentials of two hand muscles associated with either a precision or power grip exhibited significantly greater amplitudes during articulation than in passive listening, metronome, and fixation cross conditions. Moreover, these muscles exhibited similar patterns of excitability during articulation regardless of which syllable was articulated. The increased excitability of the left M1 hand area during articulation, but not during perception of the syllables, might be due to the cortico-cortical interaction between the motor representations of oral organs with the hand area.

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1. Introduction

The view concerning the association of speech and hand gestures in terms of anatomical, functional, and evolutionary connections has been suggested for decades. It is assumed that mutual interaction between mouth and hand movements initially evolved for ingestion and later followed by the formation of combined manual and vocal communication [1]. Neuroimaging studies have suggested a partially overlapping neural substrate for processing speech and manual gestures [2,3]. Transcranial magnetic stimulation (TMS) studies have shown modulation of motor evoked potentials (MEPs) elicited by stimulating the tongue and lip representations in the primary motor cortex (M1) while listening to

speech [4,5] and observing meaningful hand gestures (associated with words) [6]. Moreover, it has been demonstrated that TMS-induced MEPs increase in the hand motor area for reading aloud [7–11], teeth clenching [12–14], non-vocal oral movements [10], silent reading [10,15] and listening to speech [7].

In addition to the above-mentioned TMS studies, behavioral studies have also shown interactions between hand and mouth movements [16–19]. For instance, lip aperture increases as a function of grasping of objects with increasing size [16]. Vainio et al. [18] have recently shown that participants perform precision grip responses faster and more accurately than power grip responses if they simultaneously articulate for instance the syllable [ti] as compared to [ka]; similar improvement of power-grip responses was observed when participants articulate [ka] as compared to [ti]. This effect can be observed even when the syllable is heard or read silently [17]. Vainio et al. [18] suggested that articulations involving the tongue body and larger mouth aperture (e.g., [ka]) could be considered as an articulatory counterpart of whole hand movements

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with larger apertures, i.e. a power grip. Conversely, articulations using the tip of the tongue and smaller mouth apertures (e.g., [ti]) could be equivalent to hand movements with smaller apertures, like a precision grip. Hence, the connection between syllables and grip types could be ascribed to the oral movements required to produce those speech sounds. However, the physiological association between speech sounds and grip types has not yet been studied. One might speculate that the facilitation of hand grips during the articulation and passively listening to meaningless syllables results from the modulation of corticospinal motor excitability in the hand muscles involved in different grip actions. Consequently, we hypothesized that articulation and listening to syllables which are linked to different grasp actions (i.e., [ti] and precision grip, [ka] and power grip) result in facilitation of motor excitability of muscles involved in these two actions in a muscle-specific manner.

First dorsal interosseus (FDI) and abductor digiti minimi (ADM) muscles are considered to be dominantly involved in performing precision and power grip actions, respectively. Grasping a handle with the precision grip involves significantly greater EMG activity in FDI muscle as compared to grasping a disk with the power grip, while ADM muscle is more active for grasping of a disk than a handle [20]. TMS studies have shown that MEPs recorded from FDI and ADM muscles increase when participants observe objects congruent with the precision or power grip, respectively [21,22]. To test whether articulation and listening to the syllables associated with precision and power grip would lead to the differential modulation of corticospinal excitability in the corresponding hand muscles, we recorded the MEPs from FDI and ADM muscles of the right hand while participants were articulating or passively listening to [ti] and [ka] syllables, hearing metronome beats, or looking at a fixation cross. We hypothesized that articulating and listening to the [ti] syllable would result in an increase in excitability of FDI as compared to ADM muscle, and the effect would be reversed for the [ka] syllable (i.e., higher motor excitability in the ADM as compared to FDI muscle). If we do not find this effect, it might imply that the functional overlap between the representations of the two articulatory gestures and the precision and power grip actions might not happen in M1 and, rather, occurs in other cortical regions. Furthermore, based on the previous findings, we hypothesized that overall hand motor excitability would be higher during the articulation and (to a lesser degree) during passive listening as compared to the baseline (metronome and fixation cross) conditions.

2. Materials and methods

2.1. Participants

A total of 14 healthy right-handed native Finnish speakers participated in the experiment (2 males and 12 females, mean age: 32.35 ± 10.02) after giving their written informed consent. All participants had normal hearing. They were all rewarded for participating with movie tickets. The study was approved by the Ethical Review Board in Humanities and Social and Behavioural Sciences at the University of Helsinki.

2.2. Experimental protocol

The experimental protocol is partly adopted from Komeilipoor, et al. [23]. During the experiment, the participants were comfortably seated in an armchair in front of a computer screen. Before each trial, the number of the coming trial was displayed on the screen until the experimenter pressed a button to start the trial. Each trial started with a fixation cross, presented during all conditions. TMS-evoked MEPs were recorded from the right FDI and ADM muscles in the following condition blocks: (a) observation of

a fixation cross, (b) listening to a metronome (c) passive listening to spoken syllables ([ti]/[ka]), and (d) articulation of these two syllables. Listening and articulation condition blocks consisted of 48 trials in which the syllables [ti] and [ka] were presented or articulated 24 times in random order, equal to the number of MEPs recorded for each baseline condition (fixation and metronome). The first and the last blocks were the baseline conditions (fixation and metronome) and the listening and articulation blocks were the second and third blocks. The order of blocks (1st with 4th and 2nd with 3rd) was randomized across participants.

During (a) the fixation condition, participants were instructed to keep their gaze on the fixation cross displayed in the center of the screen during the trial. In the (b) metronome condition, participants were listening to the metronome playing six clicks at 1 s intervals while keeping their gaze on the fixation cross. The presentation of the fixation cross for metronome and fixation cross conditions was preceded by the number of each trial (from 1 to 24) displayed on the screen. After each trial, participants were asked to verbally report the observed number to ensure that they were paying attention to the task the whole time. During (c) the listening condition, participants listened to the syllables [ti] or [ka] presented in place of one of the metronome beats (i.e., 2nd, 3rd, 4th, or 5th) to reduce participants' ability to anticipate the syllable presentation and consequently the timing of TMS pulse delivery. The syllables were not presented at the first click to decrease the probability of a participant's missing the syllables and the last click was excluded to limit the timing of TMS stimulations. After each trial, the participants were asked to verbally report the heard syllable to ensure that they had heard the syllables. In (d) the articulation condition, the syllable [ti] or [ka] was written (in capital letters with KaiTi font) on the screen until the experimenter pressed the space bar of a computer keyboard to start the trial. Participants were then asked to articulate the indicated syllable in a natural talking voice in time with the metronome beats while looking at the fixation cross. The metronome was used in order to provide a cue for articulating syllables in time with the beats to ensure that TMS pulses were delivered during vocalization. Before starting the recordings, each participant performed ten trials in order to practice synchronizing their articulation with the metronome beats.

The experiment was designed using Presentation (Version 16.1, www.neurobs.com) software to control the stimulus presentation, randomization of trials and to trigger TMS pulses. The auditory stimuli were presented bilaterally to both ears using in-ear headphones at approximately 70 dB.

2.3. Transcranial magnetic stimulation (TMS)

A magnetic stimulator, a navigated brain stimulation system and a figure-of-eight coil were used to deliver the electromagnetic stimuli (Nexstim Ltd, Helsinki, Finland). The coil was placed tangentially to the scalp with its handle pointing backward and TMS was delivered to the optimal spot in the left M1; i.e. the location at which MEP of maximal amplitude was induced in both the contralateral right first dorsal interosseous (FDI) and the abductor digiti minimi (ADM) muscles. TMS intensity was adjusted to 120–130% of the resting motor threshold (RMT) in order to evoke MEP in both muscles with amplitudes larger than 1 mV. The RMT was defined as the minimum TMS intensity at which MEP with peak-to-peak amplitudes of larger than 50 μ V were induced in the FDI and ADM muscles in at least five out of ten successive trials under resting condition. The optimal stimulation spot was marked on the template MRI using the navigation system. EMG activity was recorded using paired Ag/AgCl surface electrodes from the FDI and ADM muscles of the right hand by placing surface electrodes over the muscle belly (active electrode) and over the tendon of the muscle (reference electrode). The ground electrode was placed over the right ulnar

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