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Research article

Corticospinal excitability during the processing of handwritten and typed words and non-words

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HIGHLIGHTS

- TMS was applied to left primary motor cortex during observation of videos of handwritten and typed words and non-words.
- MEPs from the FDI muscle were measured.
- Facilitation of MEPs was observed for handwritten stimuli for both words and non-words.
- Facilitation was not observed for typed stimuli.
- Motor system plays a strong role in perception of written language.

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ABSTRACT

A number of studies have suggested that perception of actions is accompanied by motor simulation of those actions. To further explore this proposal, we applied Transcranial magnetic stimulation (TMS) to the left primary motor cortex during the observation of handwritten and typed language stimuli, including words and non-word consonant clusters. We recorded motor-evoked potentials (MEPs) from the right first dorsal interosseous (FDI) muscle to measure cortico-spinal excitability during written text perception. We observed a facilitation in MEPs for handwritten stimuli, regardless of whether the stimuli were words or non-words, suggesting potential motor simulation during observation. We did not observe a similar facilitation for the typed stimuli, suggesting that motor simulation was not occurring during observation of typed text. By demonstrating potential simulation of written language text during observation, these findings add to a growing literature suggesting that the motor system plays a strong role in the perception of written language.

1. Introduction

Language is a deeply embodied system. We speak using our tongue and mouth muscles, we write using our hands, and we learn the meanings of words by observing the sensory and motor features present while hearing those words. Understanding the role that motor activation plays in each context of language processing is an ongoing enterprise. Many processes considered to be a part of the motor system have been revealed to have involvement in language [1–4]. Several competing explanations exist as to why non-motor cognition and perception would call on the motor system, including simulation theories [5–8], active prediction theories [9–11], and motor resonance theories [12].

A large body of work has looked into understanding the relationship between the motor system and language use in humans [4,13–16]. One theory called the "motor theory of speech perception", put forth by Liberman and Mattingly [17], proposed that speech perception entails mapping the acoustic patterns of sound onto the gestures that are used in their creation. Fadiga et al. [1] hypothesized that the mapping of these gestures involves mapping to their own respective motor system, in which case we should see activation of the mouth motor region of someone listening to speech. They applied single-pulse transcranial magnetic stimulation (TMS) to the cortical tongue region of participants as they passively listened to words with either a double "rr" phoneme or the double "ff" phoneme. Motor-evoked potentials (MEPs) measuring cortico-spinal excitability were obtained from the tongue muscle using electromyography (EMG). Higher MEPs were observed in the "rr" condition, whose pronunciation involves

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more movement of the tongue muscle, suggesting that participants were in fact using their own motor regions during speech perception. Skipper, Nusbaum, and Small [18] found that there was even greater increased motor activity while participants both saw and heard faces speaking, compared to only hearing or only seeing.

With the exception of Fadiga et al. and Skipper et al.'s findings, most of the research on the role of language in the motor cortex has focused on motor processing of *action-based* language, or the semantic content of language. Numerous studies, for example, provide evidence that action language, whether written or heard, and in words or full sentences, relies on the motor system for processing [14,15,19,20]. However, language is also created using the motor system. As Fadiga et al.'s findings demonstrate, hearing spoken language relies on the activation of the mouth region of the cortical motor system.

Written language has been less explored in the context of the motor system. We learn reading and writing using our sensorimotor system to write letters and words on paper or type them on a keyboard. A recent behavioral study by Beilock and Holt [21] found evidence that skilled typists may be simulating typed letters as they perceive them. They asked participants who were either expert or novice typists in an experiment to choose which of two competing letter dyads they liked better. Participants chose between a dyad of two letters that require the same finger using traditional typing methods [i.e., F, V] or a dyad of two letters that require different fingers using traditional typing methods [i.e., F, J]. They found that experts had a slight preference for the dyads that used different fingers to produce each letter, while novices did not exhibit a preference for either option. A motor task performed while making dyad preference judgments attenuated the preference of the skilled typists but only when the motor task involved the specific fingers that would be used to type the dyads. These findings suggest that in skilled typists, perceiving letters involves sensorimotor simulation of typing, which in turn influences affective judgments such as likeability.

In line with the abovementioned results, we designed an experiment to measure activation of the motor system during the perception of written language. For this purpose, we applied single-pulse TMS over left M1 and recorded MEPs from the right first dorsal interosseous (FDI) muscle in the right hand while participants saw words or non-words typed out or handwritten. We used only non-action words to avoid the recruitment of the motor system for the semantic component of action language. We predicted that during the appearance of typed or handwritten text, simulation of an inferred agent typing or writing would cause an increase in corticospinal excitability measured by MEPs. The motivation behind this experiment was twofold. The major aim was to extend theories of language embodiment to written language. We also aimed to further our understanding of the role of the motor system in non-motor processes such as language perception. While the present experiment was not aimed to distinguish between any existing theories of motor involvement, testing action observation in more and different contexts can add to this emerging area of research.

2. Methods

2.1. Participants

Twenty-four right-handed normal participants (8 males, 16 females, mean age ~19.5) were recruited in this study through UC Merced's SONA research system. All participants passed a safety screen and gave written, informed consent. The experimental procedure was approved by the UC Merced Institutional Review Board for research ethics. Participants received 2 research credits that can be used for credit in some undergraduate courses.

2.2. TMS and EMG recording

Corticospinal excitability was measured by the amplitude of motor evoked potentials (MEPs) recorded using electromyography (EMG) on the first dorsal interosseous (FDI) muscle of the right hand. MEPs were chosen as the primary measurement because we were targeting corticospinal excitability during passive observation while subjects rested their hand. Related measures also reported in the literature, such as cortical silent period or MEP recruitment curves, could provide a more detailed measure of corticospinal excitability. However, due to constraints on number of stimulations we wanted to apply to participants and the desire for passive observation, MEP amplitude was the optimal measure for our purposes. Two small adhesive electrodes ($1cm\hat{2}$) were placed over the belly of the recorded muscle and a ground electrode was placed over a bone on the participant's elbow. A bandpass filter (50 Hz–1000 Hz) was applied to the EMG signal, which was digitized at 1000 Hz for offline analysis. MEPs were elicited by applying single-pulse TMS to the FDI region of the left motor cortex. Pulses were delivered using a Magstim Rapid^{2} ™ with an attached 70 mm figure-of-eight coil positioned over the optimal scalp location with the handle pointing backward at 45° from the midline. The procedure was as follows. Subjects were fitted with a swim cap that was covered by a grid of dots placed 1 cm^2 apart. Optimal scalp position was determined by moving the coil by one centimeter intervals until the location eliciting the best MEPs was identified. This location was marked on the swim cap worn by the participant. After determining the stimulation site, we relied on Visor™ (ANT-Neuro Enschede, Netherlands) − a motion capture based neuronavigation software to ensure that the coil does not move during the duration of the experiment. This method allows for accurate repositioning throughout the experimental sessions and is consistent with the standard methods used for stimulation of M1. Resting motor threshold was determined as the percent of machine output that produced 5 out of 10 MEPs of at least 50 μV peak-to-peak amplitude. The methods described here are very similar to our previous work involving stimulation of the primary motor cortex [25,26]. The stimulation intensity during the experiment was set to 120% of a participant's resting motor threshold. The coil was held steady at the optimal position throughout the experiment. Subjects were instructed to keep their head still and remain relaxed for the duration of the experiment.

2.3. Experimental paradigm

The visual stimuli consisted of videos of either handwritten or typed words or non-words appearing letter by letter at a variable presentation speed averaging 3–4 letters per second. Non-words in this experiment were groups of consonants. Words and non-words were the same length (between 6 and 8 letters). Words were chosen that did not relate to any actions or manipulable objects, to ensure that our measurement would not be influenced by the effects of semantic processing of action. We also included 10 baseline trials, which consisted of a single black box for the same duration as the stimuli. We chose to randomize the baseline trials in with the rest of the trials so that the baseline measure would not be biased by a lack of attention that can occur when baseline measures are all recorded pre-experiment. Stimuli included five words and five non-words, which appeared four times in each of the conditions. This resulted in 80 stimulus trials and 10 baseline trials, or a total of 90 trials. Eight seconds passed in between individual trials, and the total experiment length was approximately 12 min. Because TMS stimulation would occur two seconds into the video, we ensured that the typed stimuli would display one of the following letters at that time [N, H, U, M, J, I], so that if subjects were simulating the typing, FDI would be the simulating muscle.