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Research Report

Facilitation of motor excitability during listening to spoken sentences is not modulated by noise or semantic coherence

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ABSTRACT

Comprehending speech can be particularly challenging in a noisy environment and in the absence of semantic context. It has been proposed that the articulatory motor system would be recruited especially in difficult listening conditions. However, it remains unknown how signal-to-noise ratio (SNR) and semantic context affect the recruitment of the articulatory motor system when listening to continuous speech. The aim of the present study was to address the hypothesis that involvement of the articulatory motor cortex increases when the intelligibility and clarity of the spoken sentences decreases, because of noise and the lack of semantic context. We applied Transcranial Magnetic Stimulation (TMS) to the lip and hand representations in the primary motor cortex and measured motor evoked potentials from the lip and hand muscles, respectively, to evaluate motor excitability when young adults listened to sentences. In Experiment 1, we found that the excitability of the lip motor cortex was facilitated during listening to both semantically anomalous and coherent sentences in noise relative to non-speech baselines, but neither SNR nor semantic context modulated the facilitation. In Experiment 2, we replicated these findings and found no difference in the excitability of the lip motor cortex between sentences in noise and clear sentences without noise. Thus, our results show that the articulatory motor cortex is involved in speech processing even in optimal and ecologically valid listening conditions and that its involvement is not modulated by the intelligibility and clarity of speech.

1. Introduction

Speech perception is a demanding skill that is supported by an extensive brain network. Although the human auditory system is critical for the processing of acoustic speech signals, numerous neuroimaging studies have shown that frontal cortical regions such as inferior frontal gyrus (IFG) and premotor cortex are also activated during speech perception (Adank, 2012; Callan, Callan, Gamez, Sato, & Kawato, 2010;

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Hervais-Adelman, Carlyon, Johnsrude, & Davis, 2012; Londei et al., 2010; Osnes, Hugdahl, & Specht, 2011; Pulvermüller et al., 2006; Skipper, Devlin, & Lametti, 2017; Skipper, Nusbaum, & Small, 2005; Szenkovits, Peelle, Norris, & Davis, 2012; Wilson, Saygin, Sereno, & Iacoboni, 2004). Transcranial magnetic stimulation (TMS) combined with electromyography provides a method to measure excitability of the representations of the articulators in the primary motor cortex during speech perception (Adank, Nuttall, & Kennedy-Higgins, 2017; Möttönen & Watkins, 2012; Möttönen, Rogers, & Watkins, 2014). Single TMS pulses over the representations of the articulators in the primary motor cortex elicit motor evoked potentials (MEPs) in the targeted muscles. Changes in the size of MEPs reflect changes in the excitability of the motor pathways connecting the cortical representations with the corresponding muscles. Using this technique, several studies have demonstrated that the excitability of the primary motor cortex, which controls articulatory gestures to produce speech, is enhanced during listening to speech (Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Murakami, Restle, & Ziemann, 2011; Murakami, Ugawa, & Ziemann, 2013; Nuttall, Kennedy-Higgins, Devlin, & Adank, 2017; Nuttall, Kennedy-Higgins, Hogan, Devlin, & Adank, 2016; Watkins, Strafella, & Paus, 2003).

It has been proposed that the articulatory motor system is a complementary system, recruited when listening to speech in challenging conditions (Wilson, 2009). Some MEP studies have indeed shown that listening to speech in noise enhances the excitability of the lip motor cortex more than listening to speech (sentences or syllables) without noise (Murakami et al., 2011; Nuttall et al., 2017). These MEP studies did not however include a wide range of noise levels and therefore it is currently unknown how signal-to-noise ratio (SNR) of speech signal affects the excitability of the articulatory motor cortex. Several functional Magnetic Resonance Imaging (fMRI) studies have found an increased activation in the left IFG and premotor cortex to degraded speech compared to clear speech (Adank & Devlin, 2010; Du, Buchsbaum, Grady, & Alain, 2014; Evans & Davis, 2015; Hervais-Adelman et al., 2012; Osnes et al., 2011). It is not however completely clear whether these increased frontal activations are related to increased involvement of the speech motor system in speech processing, increased involvement of additional cognitive processes (Eckert, Teubner-Rhodes, & Vaden, 2016; Peelle, 2018) or motor tasks. Recently, Du et al. (2014) investigated the activation of the motor and auditory systems during a phoneme categorization task at various SNR levels. The activation of the speech motor system (premotor cortex and posterior IFG) correlated negatively with the SNR-modulated accuracy. Furthermore, multi-voxel pattern analyses showed that the speech motor cortex successfully categorized the phonemes at lower SNR levels than the auditory system. These findings support the idea that the speech motor system has a compensatory role when categorizing speech sounds in noisy conditions. However, since the participants performed an active syllable identification task on every trial via a button press using their right hand, it is unclear whether the activations of the left primary motor cortex/pre-motor cortex were related to this task or processing of speech sounds (see for a discussion of this point Schomers & Pulvermüller, 2016). In addition, it remains unknown how SNR affects the activity of the articulatory motor system during passive listening to more natural speech signals such as sentences.

In everyday life, speech comprehension is supported by semantic context as it improves intelligibility of continuous speech in noise (Davis, Johnsrude, Hervais-Adelman, Taylor, & McGettigan, 2005; Miller & Isard, 1963; Obleser, Wise, Dresner, & Scott, 2007). For example, word report scores for semantically coherent sentences like "the coin was thrown onto the floor" are higher than for semantically anomalous sentences like "the boot was grown onto the mouth" across a wide range of SNR levels (Davis, Ford, Kherif, & Johnsrude, 2011). Neuroimaging studies have shown that semantic context affects activity in the IFG and its connectivity with other brain regions (Davis et al., 2005, 2011; Obleser et al., 2007; Sohoglu, Peelle, Carlyon, & Davis, 2012). These frontal activations are likely to be related to linguistic or semantic processing of the sentences, not speech processing in the articulatory motor cortex. It can be hypothesized that if the involvement of the articulatory motor system increases in challenging conditions, then it should show greater activation when listening to semantically anomalous sentences relative to semantically coherent sentences especially in noise.

In the present study, we aimed to address the hypothesis that the recruitment of the articulatory motor cortex increases when the intelligibility of the spoken sentences decreases and speech perception becomes more challenging. We modulated intelligibility of spoken sentences by manipulating their SNR and semantic coherence. MEPs from the lip and the hand muscles were measured while participants passively listened to semantically coherent and anomalous sentences and non-speech signals in two experiments. The aim of Experiment 1 was to test how a range of five SNR levels affects motor excitability. The aim of Experiment 2 was to test replicability of the results of Experiment 1 and to determine whether motor excitability is sensitive to the presence of noise when processing spoken sentences. Experiment 2 included sentences at two SNR levels and sentences without noise. The comparison between lip and hand MEPs allowed us to test whether listening to speech enhances excitability in the articulatory motor system specifically.

2. Materials and methods

2.1. Participants

Forty participants were recruited in Experiment 1. The data of eleven participants were excluded because of 1) unreliable motor evoked potentials (MEPs) in the lip muscle ($N = 4$), 2) artefacts in the recording preventing the accurate offline detection of lip MEPs ($N = 5$), 3) lip background muscle contraction ($N = 1$) and 4) proportion of correctly reported words for the anomalous sentences was below 40% at the highest SNR (0 dB) ($N = 1$). In total, we report the data from twenty-nine participants for Experiment 1. Thirteen participants were in the hand group (7 females −age: 24.4 ± 5.3 years old) and sixteen in the lip group (5 females − age: 22.9 ± 3.9 years old).