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Motor excitability during visual perception of known and unknown spoken languages

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ABSTRACT

It is possible to comprehend speech and discriminate languages by viewing a speaker's articulatory movements. Transcranial magnetic stimulation studies have shown that viewing speech enhances excitability in the articulatory motor cortex. Here, we investigated the specificity of this enhanced motor excitability in native and non-native speakers of English. Both groups were able to discriminate between speech movements related to a known (i.e., English) and unknown (i.e., Hebrew) language. The motor excitability was higher during observation of a known language than an unknown language or non-speech mouth movements, suggesting that motor resonance is enhanced specifically during observation of mouth movements that convey linguistic information. Surprisingly, however, the excitability was equally high during observation of a static face. Moreover, the motor excitability did not differ between native and non-native speakers. These findings suggest that the articulatory motor cortex processes several kinds of visual cues during speech communication.

1. Introduction

Viewing a speaker's articulatory movements influences speech perception. The well-known McGurk effect demonstrates that seeing an incongruent visual speech signal can modify perception of a clear auditory speech signal. For example, an auditory /ba/ and visual /ga/ are often heard as /da/ (McGurk & MacDonald, 1976). In everyday life, viewing a speaker's articulatory movements improves speech comprehension under challenging auditory circumstances, such as in noisy environments (Sumby & Pollack, 1954). However, visual speech signals are not as intelligible as auditory speech signals. For example, consonants that share the same place of articulation are hard to discriminate from each other visually (e.g., bilabials /b/, /p/, and /m/) (see, e.g., MacDonald & McGurk, 1978). Speechreading (or "lipreading") is, therefore, a demanding skill and the ability to understand visual speech varies greatly between people (MacLeod & Summerfield, 1990).

Observation of the speaker's articulatory movements facilitates learning of non-native phonetic contrasts (Hardison, 2005; Hazan, Sennema, Iba, & Faulkner, 2005; Hirata & Kelly, 2010). Studies have shown that non-native speakers use visual cues during audiovisual speech perception of their L2 and that they can learn to use these cues as efficiently as native speakers (Hardison, 1999, 2003; Hazan et al., 2006; Wang, Behne, & Jiang, 2008). There is also evidence that visual cues can enable non-native speakers to make phonetic distinctions that they are not sensitive to when only auditory cues are available (Navarra & Soto-Faroco, 2007).

It is possible to discriminate languages by viewing a speaker's articulatory movements. It has been shown that adults can visually discriminate spoken languages as long as at least one of the languages is their first (L1) or second (L2) language (Ronquest, Levi, & Pisoni, 2010; Soto-Faroco et al., 2007). Most likely, visual identification of languages is based on extracting both lexical and rhythmic information from visual speech signals (Ronquest et al., 2010). Interestingly, 4-month old monolingual and bilingual infants are able to discriminate spoken languages visually (Weikum et al., 2007). This skill, however, disappears in monolingual, but not bilingual, infants by the age of 8 months, suggesting that bilingualism enhances visual discrimination abilities in infancy (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012; Weikum et al., 2007). Nevertheless, both monolingual and bilingual adults are typically able to extract visual cues from their native or non-native languages and discriminate languages visually (Ronquest et al., 2010; Soto-Faroco et al., 2007).

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Numerous neuroimaging studies have shown that viewing a speaker's articulatory gestures activates the superior temporal cortex and the inferior frontal and premotor regions (Calvert & Campbell, 2003; Hall, Fussell, & Summerfield, 2005; Paulesu et al., 2003; Pekkola et al., 2006; Turner et al., 2009). Importantly, viewing linguistically meaningless mouth movements, i.e., gurns, does not activate these fronto-temporal regions as strongly as viewing speech movements (Campbell et al., 2001; Hall et al., 2005; Turner et al., 2009). The frontal activity has been suggested to reflect involvement of the articulatory motor system in speechreading (e.g., Campbell et al., 2001; Paulesu et al., 2003).

The role of the articulatory motor system in speech perception is under active investigation and its importance is under debate (Hickok, 2010; Hickok, Houde, & Rong, 2011; Pulvermüller & Fadiga, 2010; Scott, McGettigan, & Eisner, 2009). One of the central claims of the motor theory of speech perception is that speech perception and production are tightly linked (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985). According to this theory the speaker's intended articulatory gestures (or "neuro-motor commands") are detected from the acoustic speech signal. This inverse (from sensory to articulatory-motor) modeling has been hypothesized to activate the motor brain areas that are important for controlling articulatory movements. Indeed, such activations have been found in some neuroimaging studies during listening to speech (Pulvermüller et al., 2005; Wilson, Saygin, Sereno, & Iacoboni, 2004). Interestingly, listening to non-native speech sounds activates the motor brain regions more strongly than listening to native speech sounds, whereas native speech sounds elicit stronger activity in the superior temporal regions (Callan, Jones, Callan, & Akahane-Yamada, 2004; Wilson & Iacoboni, 2006). This suggests that enhanced articulatory-motor processing complements auditory processing of non-native speech sounds that are more ambiguous than native speech sounds. Given that access to articulatory information is more direct during visual than auditory speech perception, it is plausible that the articulatory motor cortex is engaged in visual speech perception, perhaps even more strongly than in auditory speech perception. No previous studies have investigated differences in articulatory-motor processing of native and non-native visual speech.

Transcranial Magnetic Stimulation (TMS) provides a powerful tool to investigate the excitability of the articulatory motor system during speech perception (for a review, see Möttönen and Watkins 2012). Previous studies using TMS have shown that viewing and listening to speech enhances excitability of the lip representation in the left primary motor cortex (M1) (Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Murakami, Restle, & Ziemann, 2011; Sundara, Namasivayam, & Chen, 2001; Watkins, Strafella, & Paus, 2003). These studies found that the excitability of the articulatory motor system is higher during observation of visual speech than during observation of visual noise (Murakami et al., 2011; Watkins et al., 2003), a fixation dot (Murakami et al., 2011), eye and brow movements (Watkins et al., 2003), or lateral jaw movements (Murakami et al., 2011). These control conditions either involved viewing non-biological stimuli or biological movements that are not performed by using the articulators. Therefore, the specificity of the enhanced excitability in the articulatory motor cortex during visual speech perception is unclear. If this enhanced excitability is speech-specific, viewing speech-related lip movements should excite the articulatory motor cortex more strongly than non-speech lip movements (i.e., gurns). Furthermore, if the articulatory motor cortex is involved in linking perceived articulatory gestures to internal motor codes and extracting linguistic cues from visual speech, excitability should be higher during observation of speech movements related to a known language than to a foreign language, which the observer is not experienced in producing and, which does not convey linguistic information to the observer.

In the present study, we used behavioral tasks and TMS to investigate processing of visual speech in native and non-native speakers of English. Using behavioral tasks, we measured visual language discrimination (English vs. Hebrew) and speechreading (English) skills. We aimed to determine whether our participants are able to discriminate languages visually and how language background (i.e., English as L1 or L2) influences visual speech perception skills. We also used TMS to examine the excitability of the articulatory motor cortex during observation of a known language (i.e., English), an unknown language (i.e., Hebrew), gurns and a still face. As a control, we examined the excitability of the hand motor cortex. The main aim of the TMS experiments was to examine the specificity of the excitability changes in the articulatory motor cortex. We hypothesized that the excitability in the articulatory motor cortex, but not in the hand motor cortex, is higher during observation of a known spoken language than an unknown spoken language or non-speech mouth movements. Furthermore, we aimed to determine whether the modulations of the motor excitability differ between native and non-native English speakers.

2. Materials and methods

2.1. Participants

Forty six healthy, right-handed adults participated in the study. Data from four additional participants were excluded from analysis due to unreliable MEP or artefacts in the EMG recordings. Handedness was tested using the Edinburgh Handedness Inventory (Oldfield, 1971).

Twenty four participants were native British English speakers (nine men); their mean age was 22 years (18–33 years). Native speakers were defined in this study according to the following criteria: (a) both parents spoke English at home and (b) the primary language in which they received their education up to the age of 18 years was English. Twelve native speakers were assigned to the Lip experiment and 12 were assigned to the Hand experiment.

Twenty two participants were non-native English speakers (nine men); their mean age was 26 years (20–35 years). They spoke 15 different languages as their native language. The non-native group was defined as (a) both parents spoke a language other than English at home, (b) at least until the age of 18 years, the participant had lived outside the United Kingdom in a country where English is not the dominant language, (c) the primary language in which they received education until the age of 18 years was not English. However, non-native English speakers were recruited from the UK and were, therefore, proficient enough in English to engage in employment or full time study in the UK. Average time spent as resident in the UK was 44 months. On average the non-native speakers had started learning English at the age of 11 years and estimated having become fluent at the age of 19 years. Nine non-native speakers were assigned to the Lip experiment and 13 were assigned to the Hand experiment.

All participants reported being unfamiliar with Hebrew and languages related to Hebrew such as Arabic. All participants had normal hearing and normal or corrected to normal eyesight and were screened prior to participation for contraindications to TMS. The study was performed under permission from the National Research Ethics Service.

2.2. Electromyography

In all participants electromyography (EMG) activity from the orbicularis oris (OO) muscle was recorded using two surface electrodes ($22 * 30$ mm ARBO neonatal electrocardiogram electrodes) attached on the right corners of the lower and upper lip. EMG