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Short Communication

Categorical effects in fricative perception are reflected in cortical source information

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ABSTRACT

Previous research in speech perception has shown that category information affects the discrimination of consonants to a greater extent than vowels. However, there has been little electrophysiological work on the perception of fricative sounds, which are informative for this contrast as they share properties with both consonants and vowels. In the current study we address the relative contribution of phonological and acoustic information to the perception of sibilant fricatives using event-related fields (ERFs) and dipole modeling with magnetoencephalography (MEG). We show that the field strength of neural responses peaking approximately 200 ms after sound onset co-varies with acoustic factors, while the cortical localization of earlier M100 responses suggests a stronger influence of phonological categories. We propose that neural equivalents of categorical perception for fricative sounds are best seen using localization measures, and that spectral cues are spatially coded in human cortex.

1. Introduction

The perception of speech involves the mapping of acoustic information onto discrete and language-specific phonological categories. Previous research has shown that these phonological categories strongly influence how speech is perceived: category information allows for better discrimination of acoustically equidistant sounds if they cross a category boundary than if they do not ('categorical perception', Harnad, 1987). Although within-category discrimination is still possible, it is reduced for plosive consonants such as [p–b], [t–d] and [k–g] and enhanced for vowels (Eimas, 1963; Fry, Abramson, Eimas, & Liberman, 1962; Marklund, Schwarz, & Lacerda, 2014; Pisoni, 1973). The reasons for this contrast remain unsettled but may relate to acoustic or phonological differences between vowels and plosives. Plosives are generally discriminated based on temporal cues such as voice onset time and formant transitions, whereas the discrimination of vowels relies more on their steady-state spectral properties (Drullman, Festen, & Plomp, 1994; Kewley-Port, 1983), which are spatially coded in human cortex (Obleser, Elbert, Lahiri, & Eulitz, 2003; Obleser, Lahiri, & Eulitz, 2004). Alternatively, the contrast might be driven by phonological or language-specific differences between consonants and vowels; for instance, vowels tend to occupy a prominent position in the syllable hierarchy, they can be stressed and they carry prosodic information (Spencer, 1996).

Fricatives (such as in English 'see' or 'she') can inform the reasons for this contrast since they share properties with both plosive consonants and vowels. Similarly to plosives, fricatives are consonants. However, like vowels, fricatives can be discriminated based on spectral information, as determined by the spectral peaks in the frication noise (Jongman, Wayland, & Wong, 2000). Previous research found inconsistent categorical effects for fricatives, which were discriminated categorically in some studies but not in others (Fujisaki & Kawashima, 1968; Healy & Repp, 1982; Mann & Repp, 1980; Repp, 1981). However, these studies mainly focused on behavioral tasks (for an exception, see Lipski, 2006). Here we examine whether fricative perception shows enhanced within-category discrimination, similarly to vowels, or whether it is strongly categorical, similarly to plosive consonants. We address how acoustic and phonological factors affect the discrimination of a fricative continuum from 'she' to 'see'. We use event-related fields (ERFs) in a Mismatch Negativity (MMN) design (Näätänen, Paavilainen, Rinne, & Alho, 2007; Schröger, 2005) and we model the source of the M100 response, a negative deflection that indicates sound-specific processing (Näätänen & Picton, 1987). Both the MMN amplitude and M100 dipole locations have been previously found to be sensitive to category

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membership in addition to acoustic differences (Kazanina, Phillips, & Idsardi, 2006; Obleser et al., 2004; Phillips et al., 2000). We show that both behavioral responses and the localization of the M100 component provide reliable indices of categorical processing.

2. Results

In the behavioral tests, participants performed identification and discrimination tasks on a 10-step continuum from [ʃi] to [si]. The MEG experiment comprised four blocks determined by stimuli that belonged to either the [ʃ] category ($ʃ_1$, $ʃ_2$) or to the [s] category (s_1 and s_2; Fig. 1A). These stimuli served as standards in each of the four blocks. Each block contained two types of deviants: a deviant that belonged to the same phonological category as the standard (*deviant within*) and a deviant that belonged to a different phonological category (*deviant across*), as determined by the identification test. Crucially, when the standards were $ʃ_1$ and s_1, deviants across differed from standards in category membership and they were acoustically more distant from standards than deviants within. When the standards were $ʃ_2$ and s_2, deviants across differed from standards only in category membership and they were the same acoustic distance apart from standards as deviants within (Fig. 2A).

2.1. Behavioral

In the identification task, the logistic regression revealed that the category boundary across participants corresponded approximately to step 7 in the fricative continuum (50% point = 6.89). In the discrimination task, participants showed evidence of categorical perception: acoustically equidistant pairs were discriminated more accurately when they crossed the category boundary than when they did not (Fig. 1B). Linear-mixed effects modeling revealed that participants' discrimination was influenced by both acoustic and phonological information: d' scores increased with increasing acoustic distance between the pair members (main effect of acoustic distance: $\hat{\beta} = 0.57$, $SE = 0.09$, $p < 0.01$) and they also increased when the two sounds belonged to a different phonological category than when they belonged to the same category (main effect of phonological category: $\hat{\beta} = 2.17$, $SE = 0.32$, $p < 0.01$). Importantly, there was a negative interaction between these two factors, which showed that acoustic distance had a smaller effect for across-category pairs than for within-category pairs ($\hat{\beta} = -0.47$, $SE = 0.09$, $p < 0.01$). Thus, the effect of acoustic distance was significantly modulated by the category membership of the sounds.

2.2. MEG

2.2.1. MMN amplitudes

Participants showed reliable MMN effects in posterior sites in the right and left hemispheres (*MMN right*: $\hat{\beta} = -16.18$, $t = -5.71$, $p < 0.01$; *MMN left*: $\hat{\beta} = 6.65$, $t = 2.65$, $p < 0.01$). In addition, mismatch responses were stronger on the right than on the left, as shown by a significant interaction between the MMN mean absolute amplitude and the laterality factor ($\hat{\beta} = -8.32$, $t = -2.52$, $p < 0.05$). Therefore, only right posterior sites were used in further analyses, although plots for the left hemisphere are included in the Supplementary Materials to provide a full description of the data (Fig. S2).

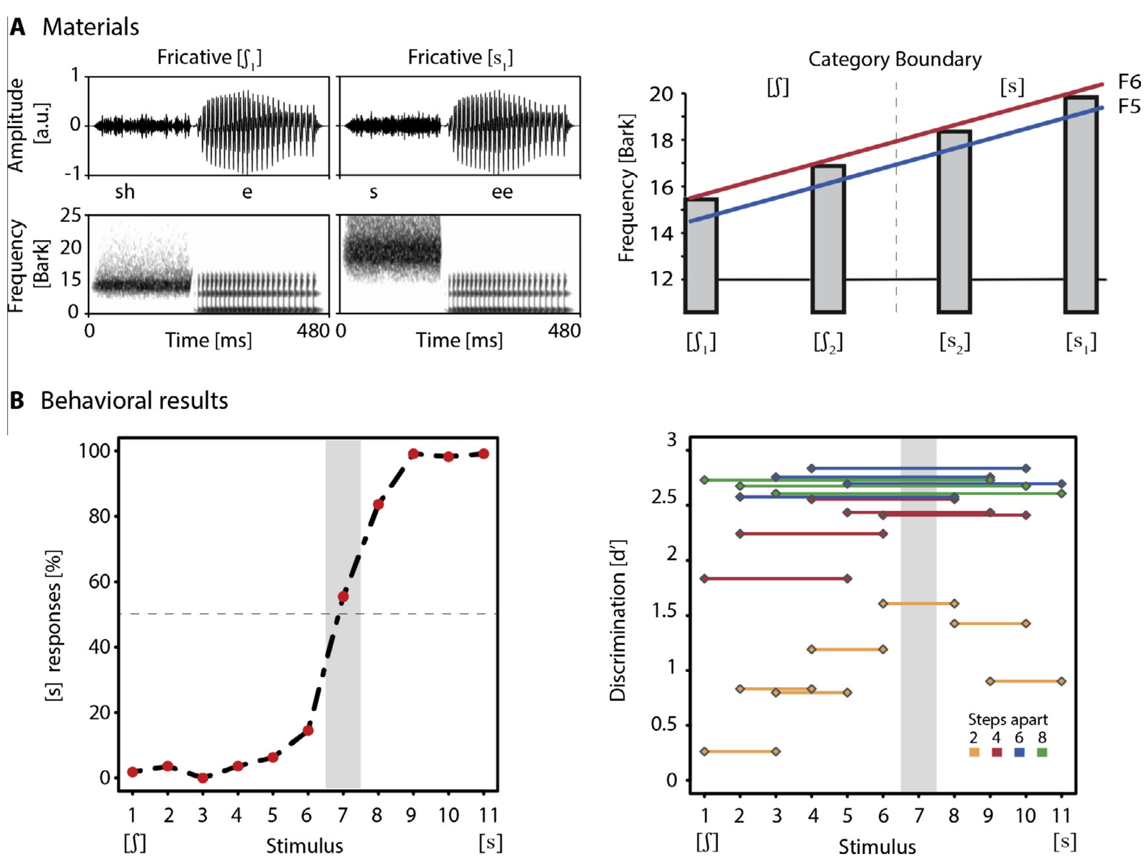

Fig. 1. (A) *left*: Wave form and spectrogram of representative stimulus used in the behavioral and MEG experiments. (A) *right*: Illustration of the MEG experiment design. (B) *left*: Results from the identification task. (B) *right*: Perceptual sensitivity expressed in d' in the discrimination task.