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Short Communication

Bilingual speech-in-noise: Neural bases of semantic context use in the native language

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ABSTRACT

Bilingual listeners comprehend speech-in-noise better in their native than non-native language. This native-language benefit is thought to arise from greater use of top-down linguistic information to assist degraded speech comprehension. Using functional magnetic resonance imaging, we recently showed that left angular gyrus activation is modulated when semantic context is used to assist native language speech-in-noise comprehension (Golestani, Hervais-Adelman, Obleser, & Scott, 2013). Here, we extend the previous work, by reanalyzing the previous data alongside the results obtained in the non-native language of the same late bilingual participants. We found a behavioral benefit of semantic context in processing speech-in-noise in the native language only, and the imaging results also revealed a native language context effect in the left angular gyrus. We also find a complementary role of lower-level auditory regions during stimulus-driven processing. Our findings help to elucidate the neural basis of the established native language behavioral benefit of speech-in-noise processing.

1. Introduction

Behavioral evidence shows speech-in-noise is more easily comprehended in the native compared to the non-native language of bilinguals (Shi, 2010). Using the Speech Perception in Noise (SPIN) paradigm (Kalikow, Stevens, & Elliott, 1977), in which the predictability of the final word in sentences is manipulated, this native language advantage has been shown to arise from better use of higher-level linguistic *contextual information* in the native than in the non-native language (Florentine, 1985; Mayo, Florentine, & Buus, 1997; Shi, 2010). Using a word-level task in which the first word of semantically related or unrelated word pairs is embedded in different levels of noise, it has further been shown that semantic context contributes to this behavioral native-language advantage (Golestani, Rosen, & Scott, 2009).

A small number of functional magnetic resonance imaging (fMRI) studies have examined the neural underpinnings of the use of linguistic context or of prior information in the comprehension of degraded speech, though only in the native language. Using the SPIN sentences, Obleser, Wise, Alex Dresner, and Scott (2007) showed that high-predictability sentences elicited greater activation in the left angular and left inferior frontal gyri (IFG) at intermediate levels of speech intelligibility. In a follow-up study, simpler noise-vocoded sentences were used, where semantic expectancy was manipulated. Greater left angular gyrus activation was found when semantic expectancy was higher, and this effect appeared to be greatest when sentences were degraded such that they were comprehensible but challenging (Obleser & Kotz, 2010). A third fMRI study addressed the question of prior information on the perception of degraded sentences, and found greater activation of the left angular and middle temporal gyri when degraded sentences were preceded by their nondegraded versions, thereby enabling extraction of semantic information (Clos et al., 2012). Fourth, in a recent fMRI study by our group, semantically related or unrelated word pairs were presented, in which the first word was embedded in noise (Golestani, Hervais-Adelman, Obleser, & Scott, 2013). We found relatively greater left angular gyrus activation in the presence of semantic contextual information, and this context effect was greater at high than low SNRs, consistent with the findings of Obleser and Kotz (2010). Finally, Zekveld, Rudner, Johnsrude, Heslenfeld, and Rönnberg (2012) recently examined how related or unrelated single-word cues influence the processing of degraded sentences. They found no evidence for modulation of neural responses during speech-in-noise processing for related over unrelated or over control, nonword cues. However, they reported that individuals with better working

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memory were better at using related cues, and this was associated with diminished superior temporal gyrus and IFG activation and increased right medial frontal cortex activation.

In the present experiment, we extend the fMRI study described above (Golestani et al., 2013) to the non-native language of late bilinguals, with the goals of replicating the behavioral native-language context benefit (Golestani et al., 2009), and of establishing, for the first time, neural evidence for the native-language specificity of this context effect. The neural basis of speech-in-noise processing has so far not been examined in both languages of bilinguals. Here, we reanalyzed previously reported data obtained in the native language (French) of our nine participants along with new data obtained in their second, late-learned 'non-native' language (English). Participants performed a forced-choice visual recognition task on the first of two auditorily-presented sematically related or unrelated words, where the first, 'target' word was embedded in different levels of noise (SNRs: −7, −6, −5 dB, and no noise). Behaviorally, we predicted relatively better performance at higher SNRs, on semantically related trials, and in the native language. Consistent with Golestani et al. (2009), we also predicted a behavioral benefit of semantic context at the lower SNRs (c.f. (Golestani et al., 2009; Mayo et al., 1997), but only in the native language. In the imaging data, we predicted modulation of left angular gyrus activation by semantic context, specifically in the native language. We also expected to find complementary involvement of lower-level auditory regions, during more stimulus-driven processing (i.e. during semantically unrelated trials, in which no supporting semantic information is available, c.f. Golestani et al., 2013) in both languages of participants.

2. Results

2.1. Behavioral results

Reaction time (RT) and accuracy data for each condition are presented in Fig. 1. A 3-way (language by context by SNR) repeated-measures ANOVA on the RTs excluding incorrect trials revealed, as predicted: (1) a main effect of language ($F_{(1,\ 8)} = 29.84$, $p = 0.001$, partial-$\eta^2 = 0.79$), with faster RTss in the native compared to the non-native language, (2) of SNR ($F_{(3,\ 24)} = 54.74$, $p = 0.001$, partial-$\eta^2 = 0.87$), with faster RTs at relatively higher SNRs, and (3) of context ($F_{(1,8)} = 42.92$, $p = 0.001$, partial-$\eta^2 = 0.57$), with faster RTs on related compared to unrelated conditions (see Fig. 1). There was a significant 2-way interaction between language and SNR ($F_{(3,24)} = 3.03$, $p = 0.049$, partial-$\eta^2 = 0.27$). There was also a significant 3-way language by context by SNR interaction ($F_{(3,\ 24)} = 4.08$, $p = 0.018$, partial-$\eta^2 = 0.34$). Post-hoc pairwise comparisons on the cells of this 3-way interaction revealed that, as predicted, there was an effect of semantic context in French only and at the lowest SNR only ($F_{(1,\ 8)} = 10.35$, $p = 0.0001$) (i.e. there was no significant advantage nor disadvantage of semantic context at any other SNR in either language), and examination of the means (mean RT related = 757 ms, mean RT unrelated = 847 ms) revealed that this context effect reflected faster performance on the semantically related compared to the unrelated trials (n.b. that the critical p-value for $\alpha = 0.05$ for eight tests is 0.006, using a Bonferroni correction). Thus, at the lowest SNR of −7, we observe a benefit of semantic context on RTs in the native language only.

Accuracy values ranged from 77% to 86% correct in the conditions containing noise (mean = 82% and SD = 1.6%), demonstrating that performance was well above chance (on a binomial distribution with $p = 0.5$, equivalent to random responding, the probability of scoring 77% correct by chance, over 30 trials = 0.002). A 3-way (language by context by SNR) repeated-measures ANOVA showed a main effect of language ($F_{(1,8)} = 13.40$, $p = 0.006$, partial-$\eta^2 = 0.63$), with relatively better performance in the native language, and a main effect of SNR ($F_{(3,24)} = 41.85$, $p = 0.001$, partial-$\eta^2 = 0.84$), with better performance on relatively higher SNRs (Fig. 1c and d).

2.2. Imaging results

Unless otherwise indicated, all results described were significant at a whole-brain familywise error corrected level of $p < 0.05$. Table 1 lists the peak voxels of the effects described below.

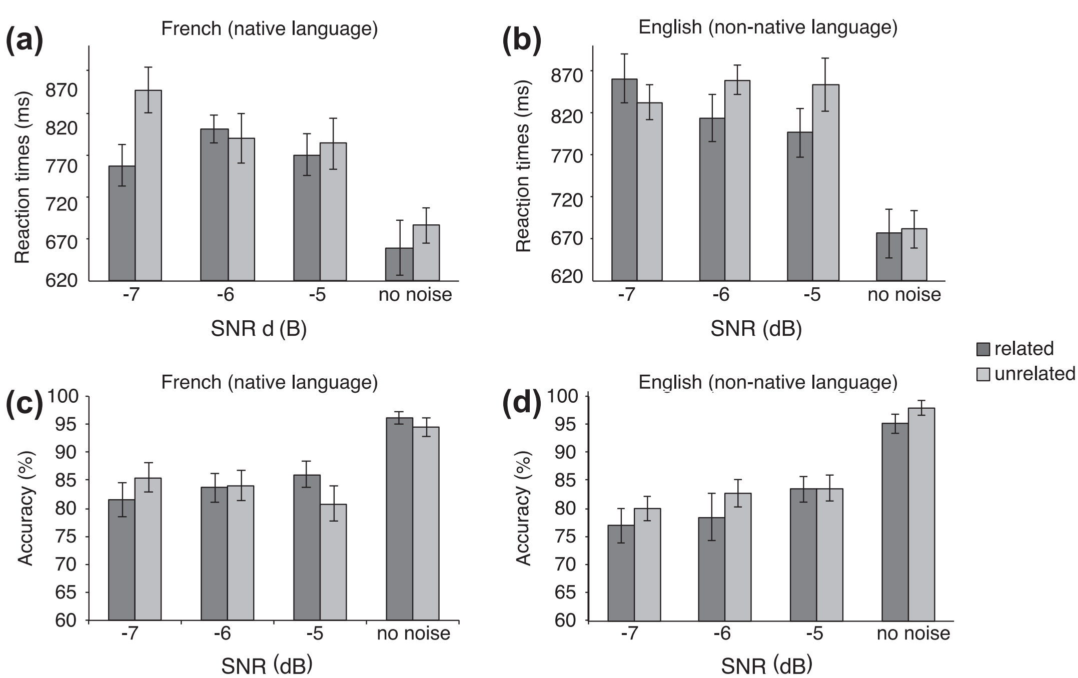

Fig. 1. Mean reaction times for behavioral responses across the group in French (a) and English (b). Error bars indicate the standard error of the mean (SEM). Note that in this and the next figures, the data obtained in the French condition have been previously reported in Golestani et al. (2013).