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Hemispheric asymmetries depend on the phonetic feature: A dichotic study of place of articulation and voicing in French stops

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ABSTRACT

Dichotic listening experiments show a right-ear advantage (REA), reflecting a left-hemisphere (LH) dominance. However, we found a decrease in REA when the initial stop consonants of two simultaneous French CVC words differed in voicing rather than place of articulation (Experiment 1). This result suggests that the right hemisphere (RH) is more involved in voicing than in place processing. The voiceless–voiced contrast is realised as short positive vs. long negative VOT in French stop consonants, but as long vs. short positive VOT in English. We tested whether the relative involvement of the LH and RH is governed by their respective putative specialisation for short and long events. As expected, in French, the REA decreased when a voiced stop was presented to the left ear and a voiceless stop to the right ear (+V −V), whereas the REA had been shown to decrease for (−V +V) pairs in English. Additionally, voiced stops were more frequently reported among blend responses when a voiced consonant was presented to the left ear. In Experiment 2, VCV pairs were used to reduce the stimulus dominance effect for voiced consonants, which probably contributed to the low REA for (+V −V) pairs in Experiment 1. The reduction of the REA due to a voicing difference was maintained, which provides evidence for the relative independence of the mechanisms responsible for stimulus dominance and perceptual asymmetries in dichotic listening. The results are discussed in the light of the Asymmetric Sampling in Time (AST) model.

1. Introduction

Speech is known to be processed preferentially by the left hemisphere in most right-handers. It is generally admitted that this hemispheric dominance can be accounted for by two competing hypotheses: (i) the linguistic hypothesis, whereby speech, whatever its acoustic content, triggers a specific processing mode most favourably associated with left brain areas and (ii) the auditory hypothesis, according to which some brain areas specialise in the processing of certain acoustic and temporal events, whether speech or non-speech.

The auditory hypothesis can be further split into two different sub-hypotheses. The first one holds that certain cerebral areas of the right hemisphere (RH) specialise in the decoding of spectral features while the left hemisphere (LH) normally engages in the processing of temporal events. The LH specialisation for temporal aspects has been evidenced by greater responses of the left Heschl's gyrus to the increased rate of temporal changes, while an increased number of spectral elements mainly recruited the right anterior superior temporal gyrus in a PET study (Zatorre & Belin, 2001). Such asymmetry for temporal and spectral processes has also been reported from electrophysiological recordings associated with CV syllables and non-verbal sounds (Liégeois-Chauvel, de Graaf, Laguitton, & Chauvel, 1999; Liégeois-Chauvel, Giraud, Badier, Marquis, & Chauvel, 2001), and by neuropsychological investigation of patients presenting with focal left or right brain damage (Johnsrude, Penhune, & Zatorre, 2000; Poeppel et al., 2004; Robin, Tranel, & Damasio, 1990; Samson & Zatorre, 1994; Sidtis & Volpe, 1988; Zatorre, 1988). Temporal processing, and then LH areas, is assumed to be strongly recruited in speech listening, because the signal is characterised by the rapidity of auditory temporal changes, which may be the basis for the overall left lateralization observed in speech perception (Binder et al., 2000; Blumstein, Tartter, Nigro, & Stalender, 1984; Schwartz & Tallal, 1980; Schönwiesner, Rübsamen, & von Cramon, 2005; Shtyrov, Kujala, Palva, Ilmoniemi, & Näätänen, 2000; Tallal, Miller, & Fitch, 1993; Tervaniemi & Hugdahl, 2003).

The second sub-hypothesis states that the superior involvement of the LH or RH depends on whether short or long events (respectively) are processed. According to the Asymmetric Sampling in Time model (AST), the apparent opposition between temporal and spectral specialisation can be derived from a more fundamental

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difference in the time scale at which acoustic cues are analysed. It is assumed that both hemispheres are sensitive to the temporal structure of information but they may differ in their temporal resolution. By analogy with the local vs. global distinction in the visual domain (Navon, 1977), LH areas may preferentially extract information from short (25–40 ms) temporal integration windows, while RH areas may extract information from larger (150–250 ms) integration windows (Poeppel, 2003). As a consequence, rapid spectral changes such as formant transitions associated with place of articulation information or rapid frequency-modulated tones may be better processed by the LH. On the contrary, RH areas may use longer integration windows, which may favour spectral information, energy envelope of syllables, prosodic phenomena, frequency-modulated sounds with slow rates of change or with long duration (Poeppel et al., 2004). On the one hand, the LH specialisation for the microstructure of temporal events has been evidenced by psychophysical and clinical research (Nicholl, 1996; Samson, Ehrié, & Baulac, 2001). On the other hand, Boemio, Fromm, Braun, and Poeppel (2005) independently varied spectral and temporal dimensions of acoustic information in an fMRI study, and observed an interaction between hemisphere and segment duration, which reflected stronger activation in the dorsal bank of the *right* superior temporal sulcus for slow modulation rates (i.e. long segment duration). A RH advantage has also been reported for the detection of long (but not short) frequency transitions (200 ms), particularly when occurring at the front of the stimulus (McKibbin, Elias, Saucier, & Engebregston, 2003).

Voicing analysis may be an interesting issue to assess the relative involvement of the LH and RH in speech processing. According to a review by Simos, Molfese, and Brenden (1997), empirical evidence does not support an unequivocal superiority of the LH in language processing. More specifically, while a tradition of studies dating back, at least, to the early 1970s (Cutting, 1974; Darwin, 1971; Haggard, 1971; Hugdahl & Andersson, 1984; Studdert-Kennedy & Schankweiler, 1970), has demonstrated that dichotic listening experiments involving stop consonants often showed a strong right-ear advantage (REA), which reflected an LH advantage, the voicing contrast has been shown to rely more heavily (than other phonemic contrasts) on the RH (Cohen, 1981). This special pattern of lateralization for the processing of voicing has been found in several studies. For instance, Cohen and Segalowitz (1990) showed that the acquisition of a non-native voicing contrast by adults was easier and quicker when the target sounds were presented to the RH rather than to the LH. Additionally, in Molfese (1978) and Segalowitz and Cohen (1989), event-related potentials were recorded while subjects listened to a series of stop consonants with varying Voice Onset Time (VOTs). The findings revealed that ERPs from the LH varied linearly (low level processing) with the VOT while those from the RH were found to vary categorically. Moreover, neuropsychological studies showed that aphasic patients, whose RH was spared, were more efficient in the processing of voicing rather than place of articulation contrasts (Blumstein, Baker, & Goodglass, 1977; Miceli, Caltagirone, Gainoti, & Payer-Rigo, 1978; Yeni-Khomshian & Lafontaine, 1983), while RH or LH unilateral brain lesions in non-aphasic patients were associated with a similar impairment in voicing processing, which suggests the role of RH areas in the categorical processing of voicing cues (Yeni-Komshian, Ludlow, Rosenberg, Fair, & Salazar, 1986).

In participants without cerebral lesions, dichotic presentation is useful to assess hemispheric lateralization for different types of phonetic features. In dichotic listening tasks, each ear is simultaneously supplied with a different speech stimulus, and the recall of information reveals a right-ear advantage (REA) in a majority of right-handers, provided that stop consonants are used. Since contralateral projections in the auditory system provide better transmission and take precedence over ipsilateral ones, the REA has been assumed to reflect the dominance of LH areas in the task (Hugdahl & Wester, 1992; Kimura, 1967; Milner, Taylor, & Sperry, 1968; Sparks & Geschwind, 1968). In 1970, Studdert-Kennedy and Shankweiler observed a larger REA when the stimuli differed by place rather than voicing, which suggests a lesser LH lateralization for voicing than for place processing. To our knowledge, this effect has not yet been replicated, except in an experiment derived from dichotic listening (Cohen, 1981). Subjects were required to rate the difference between two successive stimuli containing a consonant, while the other ear was supplied with a white noise. An LEA was observed when the stimuli differed by voicing. This categorical behaviour of the RH may reflect a possible phonological representation of voicing associated with this hemisphere.

The goal of this article is to conduct two dichotic listening experiments based on French stops in order to examine how brain functional asymmetries differ depending on whether the competing stimuli differ in voicing, place of articulation, or both, with special attention to the hypothesis that the processing of voicing involves the RH to a greater extent than that of place of articulation. While the stimuli in most previous studies within this paradigm are English stops, we used French stops instead. The reason for this stems from the fact that the phonetic implementation of voicing contrasts varies between French and English, in its acoustic and temporal cues. While in English this contrast is realised as long vs. short positive VOT (Lisker & Abramson, 1964), in French the opposition is based on short (almost null) positive vs. long negative VOT (phonologically voiceless vs. voiced stops, respectively, for both languages). The long negative VOT is composed of a periodic low-frequency sound typically spanning some 100 ms before the release of the burst (word-initially, in isolated words). This key difference is interesting in the light of the second sub-hypothesis of the auditory hypothesis, whereby short events are preferentially processed by the LH and long ones, by the RH. In accordance with this sub-hypothesis, Rimol and colleagues (2006) observed that the lowest REA in dichotic listening occurred when a long positive VOT (English voiceless stops) was presented to the left ear, while a short positive VOT (English voiced stops) was presented to the right ear.

According to the same hypothesis, we assumed that dichotic CVC riming pairs of French words would produce a lower REA when the initial consonants differed by voicing rather than by place of articulation. More precisely, since a long acoustic event (pre-voicing) occurs in French voiced stops, we predicted that this effect would be mainly due to dichotic pairs where a voiced consonant was presented to the left ear. In other words, we assumed that the magnitude of the REA could not be directly predicted by the value of the voicing phonological feature presented to the left ear – RH (voice vs. voiceless), but rather by its phonetic implementation, i.e. the duration of the VOT.

2. Experiment 1

2.1. Methods

2.1.1. Participants

The participants were 24 native French speakers (mean age 25 years 3 months, SD = 6 years; 7 males and 17 females) who were recruited at Lyon 2 University, France. They were healthy students, with no history of neurological disease. Hearing of all subjects was tested by determining ascending and descending thresholds for each ear individually for pure tones of 250, 500, 750, 1000, 2000, 4000, 6000 and 8000 Hz. No participant had inter-ear threshold differences of more than 10 dB. Overall absolute hearing thresholds for the right ear and the left ear were found to be below 20 dB, except in very few speakers whose threshold was higher for specific frequencies (typically, 6000–8000 Hz). All