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Research paper

Ear and contralateral masker effects on auditory temporal gap detection thresholds

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ABSTRACT

A temporal processing advantage is thought to underlie the left hemisphere dominance for language. One measure of a temporal processing advantage is temporal acuity or resolution. A standard paradigm for measuring auditory temporal resolution is gap detection in its "within-channel" and "between-channel" forms. Previous experiments investigating a right ear advantage for within-channel gap detection have yielded conflicting results, and between-channel gap detection has not previously been studied for ear differences. In the present study, the two types of gap detection task were employed, under each of three contralateral masking conditions (no noise, continuous noise and interrupted noise). An adaptive tracking procedure was used to measure the minimal detectable gap at each ear (and therefore, the temporal acuity of the contralateral hemisphere). A significant effect of masking noise was observed in both of the gap detection tasks. Within-channel gap threshold durations were longer in the interrupted noise condition for both ears. Between-channel gap threshold durations were shorter in the interrupted noise condition at the left ear, with a trend in the same direction at the right ear. The study found no significant difference between the ears in thresholds in either gap detection task in any of the masking conditions. This suggests that if the left cerebral hemisphere has a temporal processing advantage, then it is not in the form of acuity for temporal gap detection.

1. Introduction

There is a long history of evidence of a human left cerebral hemisphere advantage ("dominance") for language (Kimura, 1961a,b; Bryden, 1982; Hugdahl, 2000; Stefanatos et al., 2005). Precisely why language function should be dominant in the left hemisphere is not clear, but one hypothesis posits that the left hemisphere possesses a temporal processing advantage for auditory stimuli, and that this advantage is a "seed" for the development of language processing on that side (see Creese, 1999). The temporal processing advantage is demonstrated behaviorally in dichotic listening studies of normal listeners studied with speech material (e.g. Schwartz and Tallal, 1980) and in studies of unilaterally brain-damaged persons (Tallal and Newcombe, 1978; Lorenzi et al., 2000). The hypothesis has correlates in electrophysiological (Liegeois-Chauvel et al., 1999), anatomical (Musiek and Reeves, 1990) and imaging data on the human auditory cortex (Zaehle et al., 2004; Penhune et al., 1996).

One form that a temporal processing advantage might take is in auditory temporal resolution or acuity. Auditory temporal acuity is often assayed using a gap detection task which measures the shortest detectable period of silence between two "marker" sounds delimiting the silent period (Moore, 2003). Gap detection performance at a given ear likely reflects the processing acuity of the contralateral cerebral hemisphere (e.g. Efron et al., 1985), and so one might expect a right ear superiority for gap detection in normal listeners.

The gap detection task comes in two general forms. In the classical paradigm, the gap is delimited by spectrally identical sounds (Moore, 2003), and has been termed "within-channel" because the perceptual task ultimately reduces to the detection of a discontinuity in the activity of the neural-perceptual channel activated by the stimulus (Phillips et al., 1997). Using a method of constant stimuli in a one interval, two alternative forced choice design, Brown and Nicholls (1997) showed a right ear (and therefore, a left cerebral hemisphere) advantage for accuracy and speed of within-channel gap detection in white noise, but only for gap durations above detection threshold, and below ceiling performance. The right ear advantage disappears if the noise is low frequency in spectrum (Sulakhe et al., 2003). This is perhaps to be expected because low frequency noise has envelope fluctuations that listeners may confuse with the intended "gap"; the use of low frequency noise can thus elevate within-channel gap detection thresholds and

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Abbreviations: ANOVA, analysis of variance; CPU, central processing unit; dB, deciBel; F, F statistic; HL, hearing level; Hz, hertz; ms, milliseconds; N, sample size; p, probability; SD, standard deviation.

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introduce significant variance into the measurements (Eddins et al., 1992; Moore, 2003). Other authors, employing both method of constant stimuli and adaptive, threshold tracking psychophysical methodologies in listeners studied with white noise stimuli (Baker et al., 2000; also see Baker et al., 2008), have systematically failed to find evidence of ear asymmetries in gap detection.

A quite different form of gap detection is the "between-channel" task, in which the spectral content of the markers bounding the gap is different; in this task, the perceptual operation required to detect the gap involves a relative timing of the offset of activity in the channel representing the leading marker and the onset of the activity representing the trailing marker (Phillips et al., 1997). Within- and between-channel gap detection processes have grossly different acuities, viz., milliseconds for within-channel tasks, and tens of milliseconds for between-channel tasks (Phillips et al., 1997; Formby et al., 1998; Phillips and Hall, 2000; Grose et al., 2001). Between-channel thresholds often have values similar to those of voice onset time phonetic boundaries in stop consonant-vowel syllables (with which between-channel stimuli can share some spectro-temporal features: Phillips et al., 1997; Phillips and Smith, 2004). It is because the between-channel timing mechanism may have a special role in phoneme identification (Phillips et al., 1997; Phillips and Smith, 2004; Elangovan and Stuart, in press) that it may be a good candidate timing process to be exploited by a left hemisphere language system. There has been no previous investigation of ear differences in the performance of between-channel gap detection tasks.

Few studies to date have systematically employed contralateral masking noise in efforts to measure gap detection thresholds at each ear (e.g. Baker et al., 2000, 2008). The use of contralateral masking noise is important (a) because each side of the auditory forebrain receives input from both ears (Phillips and Gates, 1982; Zhang et al., 2004) and (b) to offset the effects of any inadvertant stimulus leakage to the non-studied ear. A failure to detect an ear asymmetry in auditory acuity may reflect that a monaural stimulus without contralateral masking in fact activates mechanisms in both cerebral hemispheres, which are therefore, able to contribute to the task.

The purpose of the present study was to re-examine the question of ear asymmetries in gap detection thresholds, using a set of tasks that included both within- and between-channel forms of the gap detection paradigm, and contralateral masking. The contralateral masking issue raised a new question, namely whether the masker should be an "energetic" one (e.g. a continuous white noise) or an "event" one in which the masker itself contained silent periods pseudo-randomly varied in duration and spacing (after Phillips et al., 1994; Stuart and Phillips, 1996). The issue is relevant because the auditory forebrain is particularly responsive to auditory onsets ("events") as opposed to continuous signals (Phillips et al., 2002), and because behavior-lesion studies directly implicate the auditory forebrain in behavioral gap detection (Efron et al., 1985; Kelly et al., 1996; Syka et al., 2002; Bowen et al., 2003; Stefanatos et al., 2007). The present study thus assayed gap detection at each ear separately, using both within- and between-channel tasks, and in the absence and presence of continuous and interrupted contralateral white noise maskers.

2. Methods

2.1. Participants

Twenty-four adult listeners (15 female) from 18 to 50 years of age participated in the study. All but two subjects met the following audiometric criteria: better than 20 dB hearing level (HL) at frequencies between 250 and 8000 Hz, and no HL difference between the ears greater than 10 dB at any frequency. One of the atypical subjects had a mild left ear hearing loss at 500, 6000, and 8000 Hz. The other had a mild left ear hearing loss at 750 and 1000 Hz, and a mild right ear hearing loss at 6000 Hz. Data from these two subjects were unremarkable, and they have been included in what follows. The majority of the participants were completely naïve – only two of the 24 participants had any previous experience with gap detection tasks. All procedures used in this study received ethical approval from a Dalhousie University Ethics Review Board, under protocol #2005-1150.

2.2. Stimuli and apparatus

Stimuli were digitally synthesized at a sampling frequency of 44.1 kHz and were presented via Sennheiser HD590 headphones. Stimulus delivery and data collection and analysis were performed by an Apple 8600 Powermac computer running Matlab^{TM} (The Mathworks). Subjects sat in an Eckel sound-attenuating booth, before a computer monitor and keyboard. Subject responses were made via the keyboard, and feedback was given on the monitor. The computer CPU was located outside the booth.

Each trial offered the listener a two interval, two alternative, forced choice decision. A standard stimulus and a test stimulus occurred in random order, and the task of the listener was to specify the interval containing the test stimulus. The trial structure was as follows: (i) first stimulus, (ii) 500 ms delay, (iii) second stimulus, (iv) variable delay while participant responded, (v) 700 ms delay (inter-trial interval). Visual feedback was provided at the end of each trial. The total duration of the stimuli (leading plus trailing markers) was drawn from a uniform distribution, and ranged from 350 to 450 ms; it was identical for the two stimuli (standard and test) in any given trial, but varied from trial to trial. The gap duration was added to the total duration, so that the length of the test stimulus differed from that of the standard stimulus by the duration of the gap. The gap in the test stimulus occurred randomly anywhere from 100 ms after the onset of the stimulus, to 100 ms before the end of the stimulus. The minimum leading/trailing marker duration was therefore 100 ms, and the longest was 350 ms.

In the within-channel conditions, the noise in the target ear was wideband (nominally 20 kHz). The stimuli were ramped at the beginning and end (3 ms rise and fall), with no ramps for the marker endpoints bounding the gap. There was no interruption in the standard stimulus. In the between-channel conditions, the noise in the target ear was band-limited (digitally constructed using inverse Fourier transform). The leading marker was low frequency noise (50–3000 Hz) and the trailing marker was high frequency noise (2000–6000 Hz). As in the within-channel conditions, the stimuli were ramped at the beginning and end (3 ms rise and fall). In the between-channel conditions, however, the leading and trailing markers were ramped at both ends (they each had both a rise and a fall of 3 ms). The standard stimulus therefore had a zero-duration silent period as the leading marker fell to zero and the trailing marker rose from zero. The gap in the test stimulus was additional silence inserted at the zero point.

The contralateral masking noise was always wideband (20 kHz) and began 350 ms before the first stimulus in a given trial, continued through the 500 ms between the stimuli, and ended 100 ms after the second stimulus. The interrupted noise consisted of alternating un-ramped periods of noise and silence, drawn independently from a uniform distribution (5–95 ms) and freshly constructed on each trial. Because the masking noise was wideband in spectrum and was never the target stimulus, we were not concerned about any gating artifacts in the masker. The continuous noise had a rise and fall of 5 ms.

Stimulus levels (A-weighted) were measured with an Extech (model 407750) digital sound level meter equipped with a head-