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Left hemisphere specialization for duration discrimination of musical and speech sounds

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Abstract

Hemispheric asymmetries for processing duration of non-verbal and verbal sounds were investigated in 60 right-handed subjects. Two dichotic tests with attention directed to one ear were used, one with complex tones and one with consonant–vowel syllables. Stimuli had three possible durations: 350, 500, and 650 ms. Subjects judged whether the duration of a probe was same or different compared to the duration of the target presented before it. Target and probe were part of two dichotic pairs presented with 1 s interstimulus interval and occurred on the same side. Dependent variables were reaction time and accuracy. Results showed a significant right ear advantage for both dependent variables with both complex tones and consonant–vowel syllables. This study provides behavioural evidence of a left hemisphere specialization for duration perception of both musical and speech sounds in line with the current view based on a parameter – rather than domain-specific structuring of hemispheric perceptual asymmetries.

Keywords: Sound duration; Complex tones; Consonant–vowel syllables; (Non-)verbal sounds; Dichotic listening; Right ear advantage; Hemispheric asymmetries

1. Introduction

Duration is ecologically one of the most important features of sensory stimuli. Its representation is based mainly on time perception, which remains a largely elusive notion in neuroscience (Ivry & Spencer, 2004). For instance, time flow is as salient as colour or timbre, but we do not have sensors serving specifically its perception. Moreover, duration coding involves different kinds of perceptual processes depending on the time scale. It seems that the perception of time intervals in the range of few seconds is based on fully different mechanisms compared to time perception on longer scales (Fraisse, 1963; Lewis & Miall, 2003). Another complication of temporal perception arises from the type of task. Order tasks require judgments on the position of one event in a sequence, whereas duration or length tasks are based on metrical judgments which require the analysis of elapsed time. Again, these two types of tasks are based on completely diverse perceptual mechanisms. Finally, the estimation of duration can be either explicit, as in a duration discrimination task, or implicit, as in eyeblink conditioning (Ivry & Spencer, 2004). The present research will focus on the duration perception in the short time range and on tasks involving explicit metrical judgments.

In addition, the analysis of duration in audition is possibly more important than in other sensory modalities, especially for humans. Apart from its influence on the intensity perception of very brief stimuli (Pedersen & Salomon, 1977), sound length conveys basic information for both verbal and non-verbal sounds. In human auditory communication, duration of specific parts of musical, speech or environmental sounds can carry significant information. In particular, some phonetic features of speech are defined even only by the duration of specific portions of the acoustic wave. For instance, the main difference between a voiced and a voiceless syllable lies in the duration, in the tens of milliseconds range, of the unvoiced part (voice onset time) that follows initial burst release before vowel onset (Blumstein, Myers, & Rissman, 2005; Rimol, Eichele, & Hugdahl, 2006). On a longer time scale, also prosodic cues are conveyed by duration: meanings and emotions are conveyed by tiny differences in the duration of syllables or silences in conversations, or in the duration of notes and pauses in musical interpretation.

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Due to the basic importance of sound duration perception, many investigations of the neural mechanisms underlying time processing in the auditory domain have been carried out. The findings of these studies generally concur with the presence of a complex neural network subserving temporal perception. This network consists of interconnected cortical and subcortical cerebral structures, including the inferior colliculus (Casseday, Ehrlich, & Covey, 1994) the cerebellum (Ivry, 1997), the basal ganglia (Harrington, Haaland, & Hermanowicz, 1998a; O'Boyle, Freeman, & Cody, 1996), and several regions of the cortex, particularly in the temporal lobe at the level of the supratemporal plane, the parietal and the frontal lobes (Gibbon, Malapani, Dale, & Gallistel, 1997; Harrington, Haaland, & Knight, 1998b; Ivry & Spencer, 2004).

On the contrary, as regards possible hemispheric asymmetries for the perception of sound duration and timing in the auditory domain, the results available in literature are quite contrasting. Although few studies have been specifically targeting this issue, according to an analysis of the available studies that incidentally came across the phenomenon, it is very surprising that more or less half contributes point to a left hemisphere specialization (Belin et al., 1998; Giraud et al., 2005; Ilvonen et al., 2001; Liegeois-Chauvel, de Graaf, Laguitton, & Chauvel, 1999; Molholm, Martinez, Ritter, Javitt, & Foxe, 2005; Robin, Tranel, & Damasio, 1990; Sieroka, Dosch, Specht, & Rupp, 2003; Schonwiesner, Rubsamen, & von Cramon, 2005; Zatorre & Belin, 2001) and half to a right hemisphere specialization (Belin et al., 2002; Dittmann-Balcar, Juptner, Jentzen, & Schall, 2001; Giard et al., 1994; Griffiths, Johnsrude, Dean, & Green, 1999; Harrington et al., 1998b; Paavilainen, Alho, Reinikainen, Sams, & Naatanen, 1991; Pedersen et al., 2000; Rao, Mayer, & Harrington, 2001; Rinne et al., 2005; Sysoeva, Takegata, & Naatanen, 2006; Schall, Johnston, Todd, Ward, & Michie, 2003) for the perception of duration. There are also some studies which report no asymmetries (Inouchi, Kubota, Ferrari, & Roberts, 2002; Jancke et al., 1999; Kofoed, Bak, Rahn, & Saermark, 1995; Takegata, Nakagawa, Tonoike, & Naatanen, 2004). Instead, there is substantial agreement concerning the perceptual lateralization of other aspects of sound. Evidence from neuroimaging, behavioural and patient studies indicates univocally that the perception of intensity (Brancucci, Babiloni, Rossini, & Romani, 2005; Jäncke, Shah, Posse, Grosse-Ryuken, & Müller-Gärtner, 1998), pitch (Gregory, 1982; Zatorre, 2001) and of the diverse cues of timbre (Brancucci & San Martini, 1999; Brancucci & San Martini, 2003; Samson, 2003; Samson & Zatorre, 1994) involves mainly right hemispheric structures.

The aim of the present study is to investigate the lateralization of duration perception by using dichotic listening (DL), the most employed neuropsychological technique for the study of perceptual laterality. DL consists in the simultaneous presentation of two different auditory stimuli, one at the left and the other at the right ear. It allows testing the two hemispheres separately because when the two auditory pathways convey (unnaturally) incongruent information to the auditory cortices, the ipsilateral pathways are suppressed, thus allowing the two stimuli reaching mainly the contralateral auditory cortices (Brancucci et al., 2004; Kimura, 1967). In this particular situation, testing the right ear means, with a good approximation, testing the left auditory cortex and testing the left ear means testing the right auditory cortex (Hugdahl et al., 1999; Tervianemi & Hugdahl, 2003).

The working hypothesis of this study is that a right ear advantage indicative of a left hemispheric specialization should be observed for sound duration discrimination of both musical and speech stimuli. This claim is based on the current view of hemispheric specialization which is parameter-specific rather than domain-specific structured (Zatorre, Belin, & Penhune, 2002). According to the parameter-specific hypothesis, the classical domain-related dichotomy (left-speech vs. right-music) changed to a physical dichotomy which assigns a better temporal resolution at the left auditory cortex and a better spectral resolution at the right auditory cortex (Hickok & Poeppel, 2007; Tallal & Gaab, 2006; Zatorre, 2003).

2. Materials and methods

2.1. Participants

Fifty-eight healthy subjects, 10 males and 48 females, aged from 20 to 37 years (average age = 22.7 years) participated each in two experimental sessions (musical and speech test). None of the subjects was a professional musician. They declared to have no auditory impairment. Audiometric assessment was performed, in which subjects had to press a button when a complex tone of 264 or 395 Hz, presented via earphones repeatedly with increased intensities (steps of 2.5 dBA), became perceivable. Subjects were recruited when no ($\pm$5 dBA) different hearing thresholds were present between left and right ear. Subjects' were recruited only if they scored $\geq$25 at Edinburgh Inventory (group mean $\pm$ standard error = 63.2 $\pm$ 2.7). They were distributed as follows: 21 subjects scored $\geq$75, 22 subjects scored $\geq$50 and <75, and 15 subjects scored $\geq$25 and <50.

2.2. Stimuli

In the musical test two complex tones synthesized on a Personal Computer by means of the CSound language (Vercoe, 1992) were used. The first tone had a fundamental frequency of 500 Hz and could be presented with three different durations (350, 500, and 650 ms). The second tone (masking tone) had a fundamental frequency of 550 Hz and a duration of 700 ms. Amplitude envelope of the tones contained 50 ms rise and fall times. Tones were presented at 70 dBA. Spectral composition was harmonic with eight spectral components having the following relative amplitudes: 1, 0.7, 0.5, 0.3, 0.1, 0.03, 0.01, and 0.005.

In the speech test two consonant–vowel syllables recorded from a natural female voice were used. The first syllable was the consonant–vowel syllable (/ba/) and could be presented with three different durations (350, 500, and 650 ms). The second syllable (masking syllable) was the consonant–vowel syllable (/pa/) with a duration of 700 ms. Peak amplitude of the speech stimuli was 70 dBA.

Sampling rate of all stimuli was 44,100 Hz and amplitude resolution 16 bit. The different durations of the musical stimuli were obtained by CSound programming; the ones of the verbal stimuli were obtained using the GoldWave (V.5.12, GoldWave Inc.) software. To ensure that no transient or undesired alterations were present in the stimuli, they were recorded using headphones and visually re-analysed. Phonograms of the stimuli are illustrated in Fig. 1.

2.3. Procedure

Subjects were presented with two dichotic matching-to-sample tests with focused attention, a musical test with complex tones, and a speech test with consonant–vowel syllables. The format of the tests was chosen because it allowed controlling the direction of attention (i.e. fluctuations of attentions from one ear to the other are minimized). Previous studies have shown that it allows the detection of a consistent and reliable laterality effect (Brancucci & San Martini,