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Research report

Auditory-cortex lesions impair contralateral tone-pattern detection under informational masking

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ABSTRACT

Impaired hearing contralateral to unilateral auditory-cortex lesions is typically only observed under conditions of perceptual competition, such as dichotic presentation or speech in noise. It remains unclear, however, if the source of this effect is direct competition in frequency-specific neurons, or if enhanced processing load in more distant frequencies can also impair auditory detection. To evaluate this question, we studied a group of patients with unilateral auditory-cortex lesions ($N = 14$, six left-hemispheric (LH), eight right-hemispheric (RH); four females; age range 26–72 years) and a control group ($N = 25$; 15 females; age range 18–76 years) with a target-detection task in presence of a multi-tone masker, which can produce informational masking. The results revealed reduced sensitivity for monaural target streams presented contralateral to auditory-cortex lesions, with an approximately 10% higher error rate in the contra-lesional ear. A general, bilateral reduction of target detection was only observed in a subgroup of patients, who were classified as additionally suffering from auditory neglect. These results demonstrate that auditory-cortex lesions impair monaural, contra-lesional target detection under informational masking. The finding supports the hypothesis that neural mechanisms beyond direct competition in frequency-specific neurons can be a source of impaired hearing under perceptual competition in patients with unilateral auditory-cortex lesions.

1. Introduction

Hearing is the most important sense for human communication. Prior to the decoding of speech sounds (Hickok & Poeppel, 2015), however, the major challenge for audition is the segregation of multiple, overlapping sound sources in crowded environments, such as multiple speakers in the classical cocktail party scenario (Cherry, 1953). Recent research on the neural networks supporting this auditory scene analysis (Bregman, 1990) have revealed a role for auditory cortex (Fishman, Reser, Arezzo, & Steinschneider, 2001; Gutschalk et al., 2005; Micheyl, Tian, Carlyon, & Rauschecker, 2005; Middlebrooks & Bremen, 2013), but also for neural centers at lower and higher levels of the processing hierarchy, in particular in the cochlear nucleus (Pressnitzer, Sayles, Micheyl, & Winter, 2008) and the intraparietal sulcus

Abbreviations: AC, auditory cortex; AE, absolute error; CoC, Center of Cancellation; d′, sensitivity index; DE, difference error; IMT, informational masking test; ITD, interaural time difference; LH, left-hemispheric; N+, right-hemispheric patients with signs of neglect; N–, right-hemispheric patients without signs of neglect; PPDT, psychoacoustic pattern discrimination test; RH, right-hemispheric.

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(Cusack, 2005; Teki, Chait, Kumar, von Kriegstein, & Griffiths, 2011).

It is therefore conceivable that auditory scene analysis could be impaired in patients with lesions of the auditory cortex, which are for example observed subsequent to stroke in the territory of the middle cerebral artery. However, studies that evaluated hearing deficits with auditory-cortex lesions are relatively scarce. Most evidence for lesion-related auditory deficits comes from dichotic speech tests (Broadbent, 1952; Cherry, 1953), where two different words are presented simultaneously, one to the right and the other to the left ear, and the listeners' task is to repeat both. Patients with lesions involving the auditory cortex in one side typically have problems reporting words in the contra-lesional ear (Gutschalk, Brandt, Bartsch, & Jansen, 2012; Kimura, 1961; Musiek, 1983; Schulhoff & Goodglass, 1969), a phenomenon that is known as contra-lesional extinction (Gutschalk & Dykstra, 2015). Impaired contra-lesional deviance detection (Blaettner, Scherg, & von Cramon, 1989; Gutschalk et al., 2012) and discrimination (Biedermann, Bungert, Dörrscheidt, von Cramon, & Rübsamen, 2008) have also been reported with dichotic non-speech tests, but in all cases stimuli were synchronous and with one stimulus in each ear. Evidence for predominantly contra-lesional deficits with monaural stimulation has been provided with speech-in-noise tests (Heilman, Hammer, & Wilder, 1973; Morales-Garcia & Poole, 1972; Olsen, Noffsinger, & Kurdziel, 1975). For this case, it has been suggested that the impairment is related to the degradation of speech signals caused by energetic masking at the cochlea level (Musiek & Chermak, 2015).

However, target detection in cluttered auditory scenes can also be reduced without relevant overlap of the tonotopic representation at the cochlea level, a phenomenon that has been labeled informational masking (Durlach et al., 2003; Kidd, Mason, Richards, Gallun, & Durlach, 2008; Pollack, 1975; Watson, Kelly, & Wroton, 1976) in distinction of energetic masking at the cochlea level (Delgutte, 1990). A typical configuration to produce informational masking is the random multi-tone masker, where a single tone or tone-sequence is presented amidst multiple, random masker tones (Kidd, Mason, Deliwala, Woods, & Colburn, 1994). In human auditory cortex, detected tones under informational masking evoke a late negative response (Gutschalk, Micheyl, & Oxenham, 2008), which is not evoked by missed targets (or at least the response is much smaller). Earlier evoked components in the auditory cortex did not dissociate between detected and missed targets (Gutschalk et al., 2008; Königs & Gutschalk, 2012). The negative response evoked by monaural targets is observed in the left and right auditory cortex, but the inter-hemispheric balance shows a consistent dependence on ear of presentation or lateralization by interaural time differences (ITD) (Königs & Gutschalk, 2012).

Here, we evaluated if auditory-cortex lesions impair target detection under informational masking. We tested patients with auditory-cortex lesions with a random multi-tone informational masking paradigm and compared their performance to a group of normal listeners in the same age range. Targets were isochronous sequences of six pure tones, which were presented monaurally to test for contra-lesional impairment within listeners. Four different levels of masker density were used to explore if auditory-cortex lesions interfere with the general capacity for target and masker segregation. One half of the masker tones was presented ipsilaterally to the target and the other half contralaterally, such that listeners did not know on which side the target would occur. A number of established tests were applied to confirm auditory deficits and to screen for potential signs of neglect, which may independently impair performance in patients with right-hemispheric (RH) lesions.

2. Material and methods

2.1. Patients and controls

All participants gave their written informed consent prior to their inclusion in the study, which was performed in accordance with the Declaration of Helsinki (1996 revision). The study was approved by the institutional review board of Heidelberg University Medical School. Patients with focal brain lesions were included based on a suspected extension of the lesion into the auditory cortex (AC), defined macroscopically as Heschl's gyrus and the planum temporale. Only patients who could understand the purpose of the study could be included, such that patients with severe aphasia were not enrolled. Most patients were recruited after treatment for acute stroke at the Department of Neurology of Heidelberg University Hospital. Four patients had already participated in a previous study from our lab (Gutschalk et al., 2012). Overall, 19 patients were initially enrolled. One was not included in the final analysis because the high-resolution imaging did not confirm a lesion in the auditory cortex. One patient was excluded because of severe peripheral hearing disorder, one because performance in the pre-test (dissociation of regular and irregular tone sequences) did not meet minimal requirements (see Section 2.2.1), and one because the patient himself complained about not understanding the task after repeated instructions. One patient did not reappear to finish the main test. The remaining 14 patients all showed lesions of the auditory cortex in MRI, six with left-hemispheric (LH) damage and eight with RH damage (age range 26–72 years, mean age 55.0 years, standard deviation 12.2 years; 10 males, four females). Brain lesions were due to ischemia of the middle cerebral artery (13) or to venous infarction caused by severe sinus thrombosis (one). None of the patients was in an acute state; the tests took place between 4 months and 69 months after the infarction (mean = 29 months, standard deviation 19 months).

The control group comprised 25 subjects in a similar age range (age range 18–76 years, mean age 53.4 years, standard deviation 14.9 years; 10 males, 15 females) with no history of stroke or other known brain lesions. One additional control subject was excluded from the study because of severely abnormal test results in the auditory reference tests.

2.2. Procedure

All tests were performed by patients and controls alike. Additionally to the informational masking test (IMT) that constitutes the core of this study, a number of established tests were included for comparison and to explore potential