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Research Report

Sound lateralization in subjects with callosotomy, callosal agenesis, or hemispherectomy

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Abstract

The question of whether there is a right-hemisphere dominance in the processing of auditory spatial information in human cortex as well as the role of the corpus callosum in spatial hearing functions is still a matter of debate. Here, we approached this issue by investigating two late-callosotomized subjects and one subject with agenesis of the corpus callosum, using a task of sound lateralization with variable interaural time differences. For comparison, three subjects with left or right hemispherectomy were also tested by employing identical methods. Besides a significant reduction in their acuity, subjects with total or partial section of the corpus callosum exhibited a considerable leftward bias of sound lateralization compared to normal controls. No such bias was found in the subject with callosal agenesis, but merely a marginal reduction of general acuity. Also, one subject with complete resection of the left cerebral cortex showed virtually normal performance, whereas another subject with left hemispherectomy and one subject with right hemispherectomy exhibited severe deficits, with almost total loss of sound-lateralization ability. The results obtained in subjects with callosotomy indicate that the integrity of the corpus callosum is not indispensable for preservation of sound-lateralization ability. On the other hand, transcallosal interhemispheric transfer of auditory information obviously plays a significant role in spatial hearing functions that depend on binaural cues. Moreover, these data are compatible with the general view of a dominance of the right cortical hemisphere in auditory space perception.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Auditory localization; Spatial hearing; Hemispheric asymmetry; Corpus callosum; Space perception; Human

1. Introduction

Sound localization is mainly based on processing of interaural differences in time and sound-pressure level. The auditory system is thus organized bilaterally, with a large number of interconnections between the two halves of the brain, and sound stimuli originating in the left and right hemispaces are processed in the primary auditory cortices of both hemispheres. Despite this pronounced bilaterality of the auditory system, a preference exists, at least at

Abbreviations: AMP, auditory median plane; ANOVA, analysis of variance; CAG, callosal agenesis; CC, corpus callosum; CTO, callosotomy; EEG, electroencephalography; ITD, interaural time difference; JND, just noticeable difference; LHE, left hemispherectomy; LI, laterality index; RHE, right hemispherectomy; SE, standard error of the mean

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cortical level, for processing of contralateral sound. In animals, neurons in primary auditory cortex are preferentially sensitive to contralateral sound, and unilateral lesions including the primary auditory cortex induce more severe deficits for sound localization in contralateral hemispace [22,30,46]. Also, neuroimaging studies have revealed increased activations of the human auditory cortex with contralateral monaural sound [60] or virtual spatial sound from contralateral hemispace [45]. Finally, less accurate auditory localization in contralesional hemispace has been obtained in patients with unilateral cortical damage [49,63].

In humans, this pattern of incomplete contralaterality seems to be asymmetrical, with a dominant role of the right cortical hemisphere. Sound localization seems to be more accurate in the left than in the right hemispace [7], and neuroimaging studies have shown several areas to be more strongly activated in the right cortical hemisphere during sound-localization or lateralization tasks [1,8,16,18,29, 31,39,44,58,64,66]. Also, deficits in sound-localization precision after lesions in the right hemisphere are generally reported to be more severe [53–55,61,62,65].

Auditory cortical areas of both hemispheres are interconnected via the fibers of the corpus callosum (CC). In cats, these fibers have been shown to convey auditory spatial information [27,28,50]. The question thus arises as to how much this interhemispheric transfer participates in the emergence of the asymmetric contralaterality pattern described above. Poirer et al. [48] and Lessard et al. [35] found almost normal performance in sound localization, measured through pointing, in six acallosal subjects and one early-callosotomized subject, without significant left/right asymmetries. These data need not imply functional insignificance of the CC in spatial hearing, however, but might instead indicate long-term compensatory plasticity. In order to further elucidate the role of the CC in auditory space perception, we tested two subjects with late callosotomy, using a simple task of sound lateralization that involved neither motor nor higher-order cognitive performance. For comparison, we also included one subject with callosal agenesis, three subjects with left or right hemispherectomy, and 20 healthy controls.

2. Materials and methods

2.1. Subjects with callosotomy

D.D.V. is a 40-year-old man who had his second operation, completing the full callosotomy for the relief of a generalized multifocal epilepsy, at the age of 30 years. Magnetic-resonance-imaging (MRI) scans of D.D.V., showing the extent of callosal resections, are available in Fabri et al. [15] (Fig. 2B, inset). Moreover, D.D.V. had a lesion in the first frontal circonvolution of the right hemisphere and a small lesion in the right medial parietal cortex, which probably resulted from the callosotomy surgery. Epileptogenic lesions in the left hemisphere were not detectable. D.D.V. is right-handed and has a Wechsler Adult Intelligence Scale III (WAIS III [57]) Full Scale IQ of 81. Previous experimental studies revealed that D.D.V. neglects visual stimuli in the left hemifield, which was manifest in line bisection [19] and reaction time to stimuli flashed in the left visual field [12]. These studies suggested a left-hemispheric control of attention restricted to the right side of space. A recent case study, however, described D.D.V.'s hemineglect as unusual, because his neglect was not evident when he responded by pointing to or touching the locations of the stimuli, probably because these responses were controlled by the dorsal rather than the ventral visual system [13]. Besides his manifestation of neglect, D.D.V. showed evidence of functional disconnection typical of split brain subjects, including prolonged interhemispheric transfer times, enhanced redundancy gain in simple reaction time to bilateral stimuli, and an inability to match visual stimuli across hemifields [13].

G.S. is a 44-year-old woman who has a complex partial epilepsy with secondary generalization, and a focal EEG in the right hemisphere. G.S. had undergone partial callosotomy when she was 26 years of age. The partial resection of the corpus callosum comprises the anterior 4/5, sparing the splenium. A computerized-tomography scan (CT) of G.S. is shown in Fig. 2A (inset). Moreover, CT scans in G.S. revealed a marked cranial asymmetry, indicating a larger left hemisphere. GS has a frontal lesion in the right hemisphere, which may be a result of the callosotomy surgery. She is right-handed and has an IQ in the normal range, with a WAIS III Full Scale IQ of 99 (Verbal IQ: 82; Performance IQ: 122). Both these subjects (with callosotomy) were chronically treated with antiepileptic medication. GS has not previously participated in experimental studies.

2.2. Subject with callosal agenesis

J.P. is a right-handed woman who was 37 years old at the time of testing. She was diagnosed by computerized-tomography scan with agenesis of the corpus callosum at the age of 31 years after presentation with major depression, recurrent migraines, and some left-sided weakness. No other abnormalities were found on this scan, and an electroencephalography (EEG) recording proved to be normal. An MRI scan taken a year later confirmed the diagnosis of callosal agenesis, and her anterior commissure was estimated from the scan to be 28 mm^2 in cross section (see [3]; Fig. 2C, inset). This is at least 3 times the normal area [2,14,41]. Her WAIS III scores were in the borderline-extremely low range, with Full Scale IQ of 66 (Verbal IQ: 66; Performance IQ: 74). Despite these low scores, she presented normally during experimental testing sessions, as in previous studies [3,4], and lives independently in the community with her husband of 10 years.