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Research paper

The role of the temporal pole in modulating primitive auditory memory

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HIGHLIGHTS

- A break in interaural correlation is used to study primitive auditory memory (PAM).
- Anterior temporal lobectomy (ATL) in humans does not abolish the PAM.
- Unilateral ATL shortens the temporal preservation of PAM of contralateral sounds.
- The temporal pole top-down modulates PAM of sounds entering the contralateral ear.

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ABSTRACT

Primitive auditory memory (PAM), which is recognized as the early point in the chain of the transient auditory memory system, faithfully maintains raw acoustic fine-structure signals for up to 20–30 milliseconds. The neural mechanisms underlying PAM have not been reported in the literature. Previous anatomical, brain-imaging, and neurophysiological studies have suggested that the temporal pole (TP), part of the parahippocampal region in the

in a single fused image of the source whose perceived location is around the location of the source (the precedence effect) [2–4]. The perceptual integration between the leading direct wave and the lagging reflections plays a role in suppressing the perception of distinct echoes and facilitating the recognition and localization of the source.

More interestingly, the perceptual integration can occur over a few tens of milliseconds of the lead-lag delay [5–7], suggesting that a temporal storage of the leading direct-wave signals occurs in the central nervous system. Since auditory information is processed in a temporally sequential pattern, both an auditory storage and a temporal readout of sequential auditory information from the storage are critical for organizing acoustic stimuli into auditory-image units [8]. Without such a faithful temporal storage of raw fine-structure signals of the leading wave, neither the central computation of the similarity (correlation) nor the perceptual integration between the leading and lagging waves is possible. Thus, this faithful auditory storage of raw fine-structure signals has been termed *primitive auditory memory* (PAM) and recognized as the early point in the chain of the transient auditory memory system [6,7].

The PAM is different from the traditionally defined auditory sensory memory as investigated by the mismatch negativity (MMN) of event-related potentials [e.g.,9–11], because the MMN-probed auditory memory can last up to 2–10 s and be of a long-term nature in some circumstances [12]. Thus, the PAM of acoustic details occurs at the early end of the chain of the transient auditory memory system [6]. However, the sensory memory probed by MMN encodes sensory memory updating, reflecting the representation of intersound regularities based on feature- and temporally integrated sensory stimulus information that correspond to the subjective contents of perception [12].

1.2. How to measure the temporal preservation of PAM at the perceptual level?

Interaural correlation (IAC), which is defined as the maximum cross-correlation coefficient of these two sounds across the two ears, describes the similarity of the sound waves entering the two ears [13]. The auditory system is capable of processing the IAC and expressing the processing consequence perceptually. For example, when two identical (correlated) wideband noises are simultaneously presented at the left ear and the right ear, respectively, listeners will perceive a fused compact noise image at the center of the head. However, if the IAC gradually decreases from 1 to 0, the centrally located single image dramatically changes into two (left-right) separated images [14,15]. More importantly, when an interaural delay (i.e., interaural interval) is introduced without changing the IAC, the noise image becomes increasingly diffuse with the gradual increase of the interaural delay and eventually indistinguishable from the images of the binaurally presented independent (uncorrelated) noises [16,17].

Due to the sensitivity to changes in IAC, listeners with normal hearing can easily detect an interaurally uncorrelated noise fragment embedded in the interaurally correlated noises

Table 1

Fig. 1. Reconstruction of the extent of unilateral anterior temporal lobectomy (ATL) surrounding the temporal pole (TP, centered in Brodmann Area 38) in individual patients P04 and P12, whose perceptual testing results were not included data analyses.

interval between the two presentations was 1000 ms. Frozen noises were used for each trial.

The interaural delay, with either the leaf-ear leading (50% chance) or the right-ear leading (50% chance), was systematically increased from 0 ms using an adaptive two-interval, two-alternative, forced-choice (2AFC) procedure [19]. The participant's task was to identify which of the two noise presentations contained the BIC by pressing either the left or the right button of a computer mouse. The delay threshold for detecting the BIC was tracked using a three-up-one-down paradigm [44].

For both healthy participants and patient participants, comparisons in the delay threshold for detecting the BIC were conducted between the left-ear-leading condition and the right-ear-leading condition. For patient participants, comparisons in the delay threshold were also conducted between the ipsilateral-ear-leading (related to the hemisphere with ATL) condition and the contralateral-ear-leading condition. Moreover, for patient participants, comparisons in the delay threshold were conducted between patients with ATL in the left hemisphere and those with ATL in the right hemisphere.

2.4. Data analyses

The recordings of patient's lesion location and extent, obtained from both MRIs and CT films,

Fig. 2. Reconstruction of the extent of unilateral ATL surrounding the TP in 24 individual patient participants, whose perceptual testing results were included data analyses.

gesting that the PAM of ipsilateral-ear signals and the PAM of contralateral-ear signals shared a common underlying mechanism.

4. Disscussion

The results of this study showed that both healthy controls and patients with unilateral ATL centered on the TP (due to their unilateral TLE) were able to detect a transient BIC when an interaural delay is introduced. Also, in both healthy controls and patients, although there were no significant differences in the delay threshold for detecting the BIC between the left-ear-leading condition and the right-ear-leading condition, the delay threshold under the left-ear-leading condition was significantly correlated to that under the right-ear-leading condition. Thus, the hemispheric laterality of the temporal preservation of PAM is not evident.

Both previous brain-imaging studies and previous neurophysiological recording studies have shown that activities of the dorsal part of the TP are associated with auditory memories in both humans and monkeys [28,32,33]. However, people with ATL can still retain the ability in short-term memorization of non-verbal sounds [42]. Also, the ATL appears to produce no or only minor auditory-processing deficits when it improves the seizure control in patients with TLE that is refractory to drug medication [41,43]. Clearly, there is a need to integrate the findings from studies based

Fig. 3. Individual participants' longest interaural delays (the delay thresholds) for detecting a 200-ms break in correlation (BIC) in the healthy-control group (left panel) and in the patient group (right panel) under either the left-ear-leading condition (values along the abscissa) or the right-ear-leading condition (values along the ordinate). In each of the 2 participant groups, the delay threshold under the left-ear-leading condition was significantly correlated with that under the right-ear-leading condition (the solid line, both *r* and *p* values are presented). The broken diagonal line represents the data positions at which delay thresholds under the left-ear-leading condition were identical to those under the right-ear-leading condition.

Fig. 4. Comparisons of the delay threshold for detecting the BIC in patients with unilateral ATL between the ipsilateral-ear-leading condition and the contralateral-ear-leading condition (relative to the side with ATL) for patient individuals (left panel) and patient-group means (right panel). The delay threshold under the ipsilateral-ear-leading condition was significantly correlated with that under the contralateral-ear-leading condition (the solid line, both *r* and *p* values are presented). The broken diagonal line represents the data positions at which delay thresholds under the ipsilateral-ear-leading condition were identical to those under the contralateral-ear-leading condition. *, $p < 0.05$.

on brain ablation and the findings from studies using brain-imaging and neurophysiological recordings.

This study for the first time reveals that although the unilateral ATL (with the resection of either the left or right TP) does not abolish the auditory ability to detect the BIC when an interaural delay is introduced, it significantly reduces the longest interaural interval for detecting the BIC under the listening condition with contralateral ear leading (related to the side of ATL). Moreover, the results of this study showed that the group-mean delay threshold in patients with unilateral ATL under the ipsilateral leading condition was more or less equal to that in healthy controls, and the delay threshold under the ipsilateral-ear-leading condition was also correlated to that under the contralateral-ear-leading condition across patient individuals. Thus, the TP plays a role in modulating the PAM of acoustic fine-structure signals from the contralateral ear but not in mediating the PAM.

5. Conclusions

This study for the first time provides evidence that in patients with unilateral ATL, the PAM of noise fine-structure signals from the ipsilateral ear lasted longer than that from the contralateral ear, indicating that the TP plays a role in top-down modulating the PAM of temporal fine-structure acoustic signals from the contralateral ear. In addition to the ascending pathways from the auditory cortex to the TP, the TP has descending functional connectivity to the brain structures mediating the PAM. The PAM-mediating regions and their connections with the TP will be important issues for future studies.

Moreover, the unilateral ATL-induced asymmetrical changes in transient storage of fine-structure sound information (i.e, the PAM) are useful for monitoring and estimating the effects of ATL on auditory perception.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2016.03.025.

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