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# The functional anatomy of non-verbal (pitch memory) function in left and right anterior temporal lobectomy patients

Joseph I. Tracy[a,*], R. Nick Hernandez[a], Sonal Mayekar[a], Karol Osipowicz[b], Brian Corbett[b], Mark Pascua[b], Michael R. Sperling[a], Ashwini D. Sharan[c]

[a] Department of Neurology, Thomas Jefferson University/Jefferson Medical College, United States
[b] Department of Neuroscience, Thomas Jefferson University/Jefferson Medical College, United States
[c] Department of Neurosurgery, Thomas Jefferson University/Jefferson Medical College, United States

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ABSTRACT

An fMRI pitch memory task was administered to left and right anterior temporal lobectomy (ATL) patients. The goal was to verify the neuroanatomical correlates of non-verbal memory, and to determine if pitch memory tasks can identify cognitive risk prior to ATL. The data showed that the bilateral posterior superior temporal lobes implement pitch memory in both ATL patients and NCs (normal controls), indicating that the task can be accomplished with either anterior temporal lobe resected. NCs activate the posterior temporal lobes more strongly than ATL patients during highly accurate performance. In contrast, both ATL groups activate the anterior cingulate in association with accuracy. While our data clarifies the functional neuroanatomy of pitch memory, it also indicates that such tasks do not serve well to lateralize and functionally map potentially "at risk" non-verbal memory skills prior to ATL.


## 1. Introduction

Anterior temporal lobectomy (ATL) is an effective treatment for intractable temporal lobe epilepsy. ATL consists of the total or partial extirpation of anterior regions of the temporal lobe, amygdala, uncus, hippocampus, and parahippocampal gyrus [1,2]. In the context of the dominant temporal lobe, these areas are strongly associated with various aspects of verbal episodic memory, lexical retrieval, and category knowledge. Therefore, patient outcome with regard to disruption of these crucial cognitive systems becomes a primary concern when undertaking resective procedures such as ATL [2]. While a vast amount of research has been reported on verbal episodic memory in temporal lobe epilepsy (TLE) patients [3–12], much less research has been dedicated to examining the behavioral integrity and functional anatomical correlates of non-verbal skills [8,13]. As a result of this lack of research it is much more difficult to predict the risk to skills such as non-verbal memory following resective temporal lobe surgery. Recent work on memory for pitch, using formats that call upon short-term and working memory, has suggested this function is highly dependent on the temporal lobes. In this project, we examine pitch memory in patients who have undergone either a left or right ATL to clarify the functionality of the non-dominant temporal lobe, and to assess whether such a task can be used to identify cognitive risk to non-verbal memory functions following temporal lobe surgery for intractable epilepsy.

Schlaug et al. have reported on studies of pitch memory in normal populations, generally finding that such tasks are associated with bilateral activation of the temporal lobes, often with stronger activity in the left than the right hemisphere [14–16]. For instance, Gaab et al. [15] utilized a sparse fMRI sampling paradigm in the context of a task requiring comparison of the first and last tone in a sequence (5–6 s interval between tones). They found greater left than right temporal lobe activation, with judgment accuracy associated with left supramarginal activity. Gaab et al. [14] also utilized tone sequences and a similarity judgment paradigm, and trained participants on the task. Initially, all participants showed bilateral superior temporal gyrus activation, in addition to bilateral inferior frontal and inferior parietal activation. After training, both strong and weak learners displayed bilateral superior temporal gyrus activation, along with additional left hemisphere activation sites. Schulz et al. [16] examined a tone sequence judgment task in musicians and found that both musicians and non-musicians produced bilateral superior temporal gyrus activation. Vines et al. [17] had participants perform a tone sequence judgment task during transcranial direct current stimulation over the left supramarginal

* Corresponding author at: Thomas Jefferson University/Jefferson Medical College, Jefferson Hospital for Neuroscience, 900 Walnut Street, Suite 206, Philadelphia, PA 19107, United States. Tel.: +1 215 955 4661; fax: +1 215 503 2481.
*E-mail address:* joseph.i.tracy@jefferson.edu (J.I. Tracy).

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gyrus, achieving successful knock out of performance; however, no such effect was observed when stimulating the right supramarginal gyrus. Lastly, Bidet-Caulet et al. [13] examined TLE patients using a short-term memory tone comparison task, and found both TLE groups were impaired relative to controls with no change in patient performance before or after surgery, suggesting that both temporal lobes contribute significantly to task performance. They also found that a more extensive resection was associated with more significant deficits on the task.

In contrast, Zatorre et al. [18–25] have demonstrated the importance of the right temporal lobe in pitch memory and processing in both normal controls and epilepsy patients. For instance, Zatorre and Samson [25] used a target/comparison tone task to show that patients with right ATL and patients with right frontal lesions had the most significant deficit in pitch memory relative to controls. Zatorre et al. [24] in a PET study with normal controls used an 8-tone melody task and had participants judge whether the first and last tones were similar in pitch. Several activations in frontal (right inferior frontal, bilateral mid-frontal), parietal (bilateral inferior parietal, right superior parietal), and cingulate cortex were observed, in addition to right middle temporal activation. Lastly, Grimault et al. [18] presented tone sequences of varying length and participants judged whether two sequences were similar and observed left superior temporal activation with a trend toward right superior temporal lobe activation (both Brodmann Area (BA) 22).

Based on this review, clearly the empirical data are mixed in terms of the potential lateralization of pitch memory functions. To assess the functionality of an important non-verbal skill in TLE, contribute to the cognitive neuroscience literature on the functionality of the anterior temporal lobes, and to determine the potential laterality or bilaterality of a pitch memory task as part of its evaluation for use in calculating cognitive risk and morbidity following temporal lobe surgery, we examined a non-verbal pitch working memory task in both normal controls (NCs) and ATL patients. If the bilateral temporal lobes are needed for the task, as the work by Schlaug and others suggest, one would expect both left ATL and right ATL groups (LATL and RATL, respectively) to be impaired. If, on the other hand, one were to follow reports by Zatorre et al., one would expect the RATL group to be more significantly impaired on the task. Behaviorally, we hypothesize that both left and right ATL groups will perform with less accurately than normal controls.

## 2. Methods

### 2.1. Subjects

A total of five LATL subjects, five RATL subjects, and five NCs were recruited from the Thomas Jefferson Comprehensive Epilepsy Center for this study. The LATL group consisted of subjects who had received a left anterior temporal lobectomy as treatment for intractable left temporal lobe epilepsy. The RATL group consisted of subjects who had received a right anterior temporal lobectomy as treatment for intractable right temporal lobe epilepsy. Details of the Thomas Jefferson Comprehensive Epilepsy Center algorithm are described in Sperling et al. [26]. The anterior temporal lobectomy (ATL) involves an standardized "en bloc" resection including amygdalohippocampalectomy. Briefly, this resection includes the entire temporal pole, extending approximately 4 cm posteriorly to include the anterior regions of the parahippocampal, and superior/middle/inferior temporal gyri, and medially to include the uncus and mesial structures. The standard extirpated regions are well depicted in the Figures rendered in our results section (e.g., Fig. 2). All ATL subjects underwent surgery at least six months prior to being scanned at the Thomas Jefferson Comprehensive

**Table 1**
Patient demographic and clinical data.

| Patient # | Age (years) | Sex | Edinburgh score[a] | Neuropathology[b] | Type of seizures | Seizure freq. in past year (SZs/month) | Duration of epilepsy (years) | Education (years) | MRI findings[c] | Surgery type[d] | Surgery to scan interval (months) | FSIQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 55 | F | 80 | Idiopathic | CPS, SPS | 35 | 45 | 18 | LMTS | SLTL | 54 | 116 |
| 2 | 50 | M | 80 | Head injury (LOC) | CPS, 2°GTC | 1 | 18 | 13 | IRTH | SRTL | 6 | 99 |
| 3 | 43 | F | 36 | MTS | CPS | 8 | 43 | 12 | LMTS | MLTL | 6 | 101 |
| 4 | 31 | F | 89 | Idiopathic | CPS, 2°GTC | 10 | 1.5 | 14 | Normal | SLTL | 6 | 104 |
| 5 | 39 | M | 80 | MTS | SPS, CPS | 30 | 9 | 14 | LMTS, ILMTSI, ILTH | SLTL | 18 | 97 |
| 6 | 40 | F | 100 | MTS | CPS, TC | 4 | 25 | 13 | LMTS | SLTL | 6 | 102 |
| 7 | 29 | F | 80 | MTS | CPS, SPS | 2 | 2 | 12 | Normal | MRTL | 12 | 105 |
| 8 | 32 | F | 100 | MTS | SPS, CPS, 2°GTC | 15 | 27 | 16 | RMTS | SRTL | 6 | 96 |
| 9 | 29 | M | 80 | Idiopathic | CPS, SPS | 2.5 | 23 | 16 | Normal | SRTL | 28 | 94 |
| 10 | 45 | M | 56 | MTS | CPS, TC, SPS | 2 | 41 | 13 | RMTS, IRTH, HA | SRTL | 65 | 102 |

[a] Edinburgh score of 100 indicates complete right handedness.
[b] LOC, loss of conciousness; MTS, mesial temporal sclerosis.
[c] LMTS, left mesial temporal sclerosis; IRTH, increased right temporal horn relative to left; ILMTSI, increased left mesial temporal signal intensity; ILTH, increased left temporal horn relative to right; RMTS, right mesial temporal sclerosis; HA, hippocampus asymmetry (left larger than right).
[d] SLTL, standard left temporal lobectomy; SRTL, standard right temporal lobectomy; MLTL, modified left temporal lobectomy; MRTL, modified right temporal lobectomy.