The right-ear advantage for dichotic listening of speech-related stimuli is predicted by both attentional and structural factors: results from machine-learning analysis of neuroimaging data

Vincent J Schmithorst[1], Rola Farah[2], and Robert W Keith[2]

[1]*Radiology, Children's Hospital of Pittsburgh of UPMC, Pittsburgh, PA, United States,* [2]*Audiology, University of Cincinnati, Cincinnati, OH, United States*

Introduction

During dichotic presentation of speech-related stimuli, participants recall with greater accuracy, on average, the stimuli presented to their right ear, as opposed to their left ear [1]. However, not every individual shows a right-ear advantage (REA); approximately 15 – 20% of right-handed individuals exhibit either no ear advantage or a left-ear advantage (LEA) [2]. In this study we use multi-voxel pattern analysis (MVPA) techniques on neuroimaging data to predict whether a given individual will show a REA or a LEA.

Materials and Methods

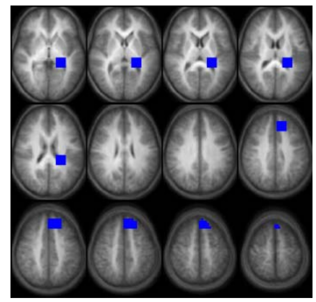
The study cohort included children ages 7-14 years of age. Children were classified as either REA or LEA based on results from the competing words (CW) subtest of the SCAN-3:C battery [3]. Subjects were presented with 20 word pairs and asked to repeat them in any order (a dichotic free-recall condition).

fMRI Scans: All scans were acquired on a Philips 3T Achieva system. Usable data was acquired from 12 REA (10 M, 2 F) and 12 LEA (10 M, 2F) children. A clustered-volume event-related paradigm was used, similar to that used in a previously published study [4]. The stimuli consisted of word pairs from the CW test. For the control task, the word pairs were presented diotically, one word following the other. Pre-processing involved: motion-correction, discarding frames that did not meet a cost function threshold for excessive motion, performing a GLM on each set of scans (1^{st}, 2^{nd}, or 3^{rd}) after the stimulus presentation period, converting the results into a single Z-score map, and transforming into Talairach space.

DTI Scans: The 15-direction standard Philips EPI-DTI sequence was used. Usable data was acquired from 14 REA (12 M, 2F) and 10 LEA (8 M, 2 F) children. Pre-processing involved: visual inspection for gross motion artifacts, computation of fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD) maps, and transformation into standard Montreal Neurological Institute (MNI) space.

MVPA Analyses: The MVPA analyses were performed using a 5-X-5-X-5 searchlight and a Gaussian Naïve Bayes (GNB) classifier, and only included voxels for which each subject had a usable data point. The classifier accuracy was estimated using leave-one-out cross-validation (LOOCV). Voxels were selected from the training set by averaging values over the 5-X-5-X-5 cube centered over each voxel, ranking voxels based on performance of the GNB classifier (using LOOCV), and selecting the number of voxels (from the best-ranked) by again estimating performance of the GNB classifier using LOOCV. The GNB was then trained using the selected voxels, and these parameters were then used to classify the test subject.

Figure 1. Regions found to predict LEA or REA for the functional contrast of listening to words presented dichotically vs. words presented diotically. (Images in radiologic orientation; slice locations: Z = +1 mm to Z = +56 mm, Talairach coordinate system.)



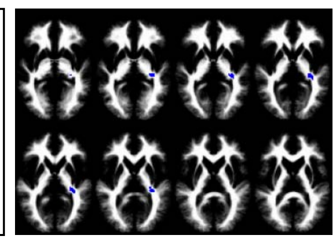
Results

As expected, based on the study design, there were significant differences in performances in the left and right ears based on ear advantage ($p < 0.01$); however, there were no significant differences in age, sex, or motion (e.g. for fMRI the number of retained frames meeting the cost threshold).

fMRI: The classifier accuracy was 83.3%, significantly different from chance ($p < 0.001$). The relevant regions (Figure 1) involve the left frontal eye fields (BA 8) and left thalamus. Greater activation was shown in BA 8 for children in REA during the *diotic* task ($p < 0.001$, unpaired T-test). No difference in mean activation was shown in the thalamus; however, the *variance* was significantly greater in children with LEA ($F(11,11) = 10.7$, $p < 0.001$), and this activation correlated with age in the children with LEA at a trend level ($R = -0.52$, $p < 0.1$).

DTI: No classifier was successfully trained for FA, MD, or RD. For AD, however, the accuracy was 75%, significantly different from chance ($p < 0.02$). The relevant region is the left internal capsule, in the sublenticular part (Figure 2). Probabilistic tractography (data not shown) revealed the most likely connections to be between the posterior part of the thalamus and the auditory cortex, indicating the relevant tract to be the auditory radiations.

Figure 2. Region found to predict LEA or REA for AD. (Images in radiologic orientation; slice locations: Z = -2 mm to Z = +12 mm, MNI coordinate system.)



Discussion

There are two main types of models posited to explain the REA. In the structural model [5], the weaker ipsilateral connections in the auditory pathway are suppressed (via a hypothesized "occlusion" mechanism) during presentation of dichotic stimuli. In the attentional model [6], the processing of language stimuli in the left hemisphere biases subsequent attention towards the contralateral (right) hemisphere. Our results show that neither the structural model nor the attentional model is sufficient by itself to explain the REA. Consistent with the structural model, impaired connectivity between the thalamus and the auditory cortex in the left hemisphere (indicated by increased AD), is likely the result of inflammation [7] and results in a LEA. However, consistent with the attentional model, LEA is also predicted by differential activation in the frontal eye fields, which bias attention contralaterally towards the right side of space. The increased variance in the thalamus in children with LEA could be the result of an age-related compensatory mechanism involving top-down efferent connectivity, although further research will be necessary. We hypothesize that the REA is a result of both the intrinsic structure of auditory pathways and the directional bias of attention to the right for stimuli processed in the left hemisphere. This framework agrees with a recent study showing interactions between top-down (free-recall vs. focused attention) and bottom-up (interaural intensity difference) factors [8].

Conclusion

REA in children for dichotic listening involving speech-related stimuli was predicted by lesser AD in the sublenticular part of the left internal capsule and greater functional activation in the left frontal eye fields during diotic presentation vs. dichotic presentation. Results suggest the etiology of REA in children is not explained solely either by a structural or an attentional model.

References

[1] Hugdahl, K. In: Hugdahl, K. (Ed.), *The Asymmetrical Brain*, 441-476, 2002. [2] Bryden, M. P. In: Hugdahl, K (Ed.), *Handbook of dichotic listening*, 1-43, 1988. [3] Keith, R. *SCAN-3 for Children: Tests for Auditory Processing Disorders*, 2009. [4] van den Noort, M., et al. *Neuroimage*, 40, 902-911, 2008. [5] Kimura, D. *Cortex*, 3, 163-168, 1967. [6] Kinsbourne, M. *Acta Psychol (Amst)*, 33, 193-201, 1970. [7] Naismith, R.T., et al. *Neurology*, 72, 589-594, 2009. [8] Westerhausen, R., et al. *Brain Res*, 1250, 183-189, 2009.