Different higher-order auditory processing tasks show differing correlations with white matter microstructure in normal-hearing children

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Introduction

In regionally specific areas, fractional anisotropy (FA) has been shown to be correlated with intelligence in normal children [1], and specific cognitive tasks such as reading ability [2]. Here we investigate possible correlations between FA and performance on higher-order auditory processing tasks often used to diagnose auditory processing disorder (APD) in children, who have normal peripheral hearing but suffer from deficits in performance on higher-order processing tasks.

Materials and Methods

The subject population consisted of 17 normally-hearing children (11 M, 6 F), ages 9-11 years. Normal hearing in both ears was verified via standard pure-tone audiometry. The tests of higher-order auditory processing skills included **SCAN-C Filtered Words** (SCANC), one syllable words that have been low-pass filtered at 1000 Hz with a roll-off of 32 dB per octave; **BKB-SIN Speech in Noise** (BKBSIN), sentences presented by a male talker over four-talker babble; and **Time-Compressed Sentences**, consisting of sentences with 40% time compression (TC40) and 60% time compression (TC60). The audiologic tests were pre-recorded and administered through a calibrated audiometer in a soundproof booth.

MRI scans were acquired on a Siemens 3T Trio system. EPI-DTI scan parameters were: TR = 6000 ms, TE = 87 ms, FOV = 25.6 X 25.6 cm, slice thickness = 2 mm, matrix = 128 X 128, b-value = 1000 s/mm^2. One scan was acquired without diffusion weighting, and 12 diffusion-weighted scans were acquired. The DTI data was visually inspected for artifacts from head motion. Spatial normalization and whole-brain segmentation was performed using SPM5 (Wellcome Dept. of Cognitive Neurology, London, UK). White matter probability maps were normalized to a white matter pediatric template; the FA maps were transformed into the MNI space and co-registered using a rigid-body transformation to the white matter probability maps. Analysis was restricted to voxels with a white matter posterior probability of > 0.9 and FA > 0.25; globally, analysis was restricted to voxels in which the above criteria were met for at least half of the subjects. Data was analyzed using the General Linear Model (GLM) with age, sex, and full-scale IQ entered as nuisance variables, and performance on the auditory processing tasks as the variable of interest, using in-house software written in IDL (ITT Visual Information Systems., Boulder, CO). Z-score maps were filtered with a Gaussian filter of width 3 mm; the filtering was restricted to voxels inside the white matter mask [1]. A Monte Carlo simulation, based on the method of [3], was used to estimate corrected p-values. A double-tailed threshold of $p < 0.05$ was used for significance.

Results and Discussion

Results are shown in Figure 1. For the three more difficult tasks (BKBSIN, SCANC, TC60), negative correlations were found between task performance and FA in the corticospinal tract. A recently proposed framework for speech processing [4] places the premotor cortex in the "dorsal stream" used for auditory-motor mapping. Stored auditory vocal templates, based on experience of one's own vocal output, may assist in recognition of speech sounds despite variations due to the characteristics of the particular speaker [5]. However, in the presence of significantly degraded speech, the template-matching process may fail as the degraded speech is too far away in the auditory-motor space from a target. We hypothesize that the auditory-motor template matching process is useful when children start to learn to speak and understand language, or perhaps when

Figure 1. Regions with positive (orange) and negative (blue) correlations of FA with four auditory processing tasks: speech-in-noise (top left), low-pass filtered words (top right), 60% time-compressed sentences (bottom left), and 40% time-compressed sentences (bottom right) in normal-hearing children ages 9-11 years. All images in radiologic orientation.

individuals learn a new language with unfamiliar phonemes; however, over time, children begin to use the more ventral processing stream for comprehension and speech recognition [4], and thus "directly" generate semantic information from the incoming auditory stream. The positive correlation with TC40 task performance likely reflects either auditory efferent control or subvocal articulatory representations carried by the dorsal pathway in order to maintain specific words in memory over a short period of time.

Correlations of FA with task performance were also found in the dorsal prefrontal cortex (BKBSIN, SCANC, TC60) as well as two more closely located areas that were more ventrally located (SCANC, TC60). The prefrontal cortex is involved in working memory and such top-down processes are known to support retrieval of information from degraded speech [6], by manipulating the degraded stimuli within short-term memory, and then reconstructed by processing within the context of semantic predictability; an alternative explanation is that the prefrontal cortex is involved with directing attention to relevant auditory features, including monitoring and selection. More ventrally situated prefrontal white matter was seen for SCANC and for TC60. This region of the prefrontal cortex may be involved with lexical selection involved with multiple word candidates [7]. The SCANC was also the only auditory processing task which displayed correlations with interhemispheric structures (the corpus callosum). In this case the subjects are likely using prosodic information to help with lexical decision. Positive correlations between FA and white matter adjoining occipital or occipital-temporal areas (BA 39) were found for the SCANC and the TC40. BA 39 is held in the model of [4] to be the more posterior region of the ventral stream, corresponding to the lexical interface linking phonological and semantic information. Better conversion from phonologic to semantic information would result in better recall from working memory when subjects are tested. For the SCANC task, a more "automatic" conversion using the ventral stream would be expected to facilitate recognition of the words.

Conclusion

The relation between brain anatomical connectivity and performance on higher-order auditory processing tasks was investigated a cohort of normal-hearing children ages 9-11. Our results support a dual-stream (dorsal and ventral) model of auditory processing, and that higher-order auditory processing tasks rely less on the dorsal stream related to articulatory networks, and more on the ventral stream related to semantic comprehension.

References

[1] Schmithorst VJ, Wilke M, Dardzinski BJ, et al., Hum Brain Mapp, 26, 139-147, 2005. [2] Qiu D, Tan LH, Zhou K, et al., Neuroimage, 41, 223-32, 2008. [3] Ledberg A, Akerman S, Roland PE, Neuroimage, 8, 113-28, 1998. [4] Hickok G, Poeppel D, Nat Rev Neurosci, 8, 393-402, 2007. [5] Kuhl PK, Nat Rev Neurosci, 5, 831-43, 2004. [6] Hannemann R, Obleser J, Eulitz C, Brain Res, 1153, 134-43, 2007. [7] Kan IP, Thompson-Schill SL, Cogn Af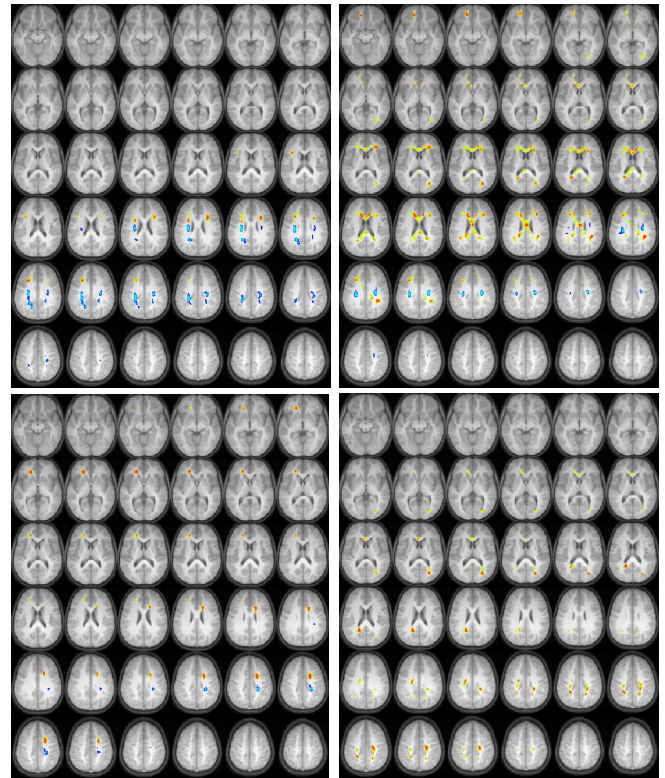fect Behav Neurosci, 4, 466-82, 2004.