Diffusion Tensor Imaging of Rat Brains Following Long-term Passive Acoustic Exposure at Moderate Sound Pressure Level

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Target Audience: Neuroanatomists, diffusion tensor imaging (DTI) researchers, audiologists, and occupational therapists

Purpose: Long-term acoustic exposure can affect the structure of the auditory system (1). Acoustic exposure is necessary for the development of the auditory system while high sound pressure level (SPL) exposures can damage it (2). Studies about the effect of acoustic exposure on the auditory system have examined functional changes in electrophysiology or behavior. In contrast, diffusion tensor imaging (DTI) can be used to identify structures morphologically modified. Identification of structural changes in the brain following long-term acoustic exposure can help explain the roles of various structures in the auditory system.

Methods: Animals: Female Sprague-Dawley rats (n=16) were employed; eight were randomly assigned to receive continuous acoustic exposure while the remaining eight were assigned to standard housing. Acoustic exposure: Acoustic exposure began when the rats were three months old. A 5Hz pulse train with a 50ms pulse duration, a 30kHz low-pass filter, and 65dB total SPL ran 24hrs/day for 2 months. MRI Protocols: The rats were anesthetized with 3% isoflurane for induction then maintained with 1.5-2%. The rats were scanned using a 7T MRI scanner (Bruker Biospin). Diffusion-weighted images (DWI) were acquired using a SE 4-shot EPI sequence with 30 diffusion gradient directions. Five images with b-value=0 (b_0 images) were also acquired. The imaging parameters were: TR/TE=3000/31.6ms, δ/Δ=5/17ms, NEX=4, FOV=3.2 x3.2cm^2, MTX=128x128, 12 slices each 1mm thick (0.18mm gap), b-value = 1000s/mm^2. Data analysis: Diffusion tensor maps for fractional anisotropy (FA) and mean diffusivity (MD) were generated. The DWIs and b_0 images of the 16 rats were co-registered and normalized to the b_0 image of an exposure rat (SPM8, Wellcome Trust Centre). A voxel-wise t-test was performed between the FA maps of the control and exposure rats. Structures indicated by VBS were identified using a rat neuroanatomy atlas (3). The atlas was used to draw a ROI for each identified structure in the slices which were indicated by VBS. The ROIs were then positioned on the unnormalized DWI of each rat and applied to FA and MD maps (Fig. 1A).

Results: The VBS are displayed by Fig. 1B which shows clusters with at least 50 voxels in which the FA of the exposure rats was significantly ($p<0.0005$) greater than those of the control rats. The ROI analysis is displayed by Fig. 2 which compares the mean values of FA and MD of the exposure and control rats in the pyramidal tract, tectospinal tract, and trigeminothalamic tract. FA was higher and MD was lower in the pyramidal tract, tectospinal tract, and trigeminothalamic tract of exposure rats than of control rats.

Discussion: VBS revealed significant increases of FA and decreases of MD in the white matter tracts of the medulla oblongata. ROI analysis argued against normalization/registration errors contributing significantly to the VBS results. This study was unique in that it used DTI to identify structures morphologically altered by long-term acoustic exposure. The trigeminothalamic tract carries sensory information from the surface of the ears so it may be affected by long-term acoustic exposure (4). The medial lemniscus and trigeminothalamic tract are intertwined at the position where VBS identified the trigeminothalamic tract making it possible for the observed changes to have occurred in the medial lemniscus. The pyramidal tract and the tectospinal tract coordinate the movement of the cranial muscles in response to external stimuli (5-6). Given the strong acoustic reflexes of rats, long-term acoustic exposure may have affected the nerves innervating the cranial muscles. The structures identified by this study further expand the diverse list of structures identified by DTI studies as being related to the auditory system.

DTI studies on blast-induced brain injury in the auditory system of mice have found associated decreased FA and increased apparent diffusion coefficient which were attributed with decreased axonal integrity and increased myelin injury, respectively (7). A number of studies in humans have found a positive correlation between the FA of the auditory system and age, with the common conclusion that increased FA reflects increased organization and development (8). Additional human-based studies have found that sensorineural hearing loss is associated with decreased FA and increased radial diffusivity in the lateral lemniscus and inferior colliculus (9). A study conducted on individuals who had suffered blast-related traumatic injury found that FA of the pyramidal tract was positively correlated with total words recalled while apparent diffusion coefficient of the uncinate fasciculi and posterior internal capsule was negatively correlated with verbal memory (10). Though the structures identified by these studies differ, a consistent conclusion is that a decrease in FA and an increase in MD of white matter is consistent with blast-induced injury of the auditory system while an increase in FA and a decrease in MD is consistent with organization of the auditory system. The results of our study suggest that long-term acoustic exposure of moderate SPL stimulates increased organization of white matter structures in the medulla oblongata in a manner consistent with known DTI indicators of increased organization of white matter structures in the auditory system. These results warrant further research into the role of the medulla oblongata in the auditory system, the effects of acoustic exposures of different SPLs on brain morphology, and the effects of common environmental conditions on neurophysiology.

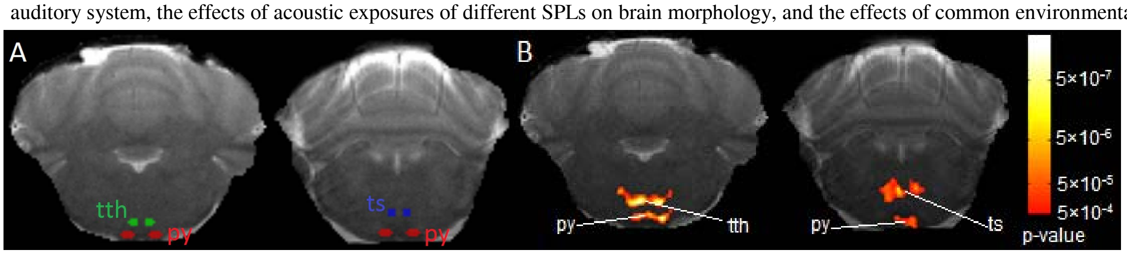

Fig. 1. A. ROIs of the pyramidal tract (py), tectospinal tract (ts), and the trigeminothalamic tract (tth). B. Clusters identified by VBS to contain significant differences in FA between the control and exposure groups are overlaid onto T2 maps. Clusters contain at least 50 voxels each with $p<0.0005$.

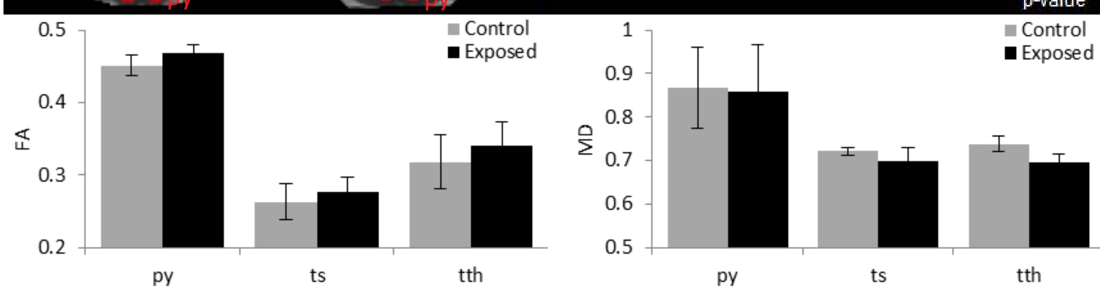

Fig. 2. Mean ± standard deviation of the FA and MD values of control and exposed rats in the pyramidal tract (py), tectospinal tract (ts), and the trigeminothalamic tract (tth).

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