ICA analysis of brachial plexus injury in an animal model reveals rapid brain plasticity in 9.4 T

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Introduction

Cortical plasticity caused by nerve injury has been demonstrated by many groups using fMRI, seed-voxel-based fcMRI, and principal component analysis (PCA). But there is no literature that uses independent component analysis (ICA), which is more effective in showing the whole-brain functional network and is independent of variables caused by systemic noise. This study compares ICA results between a healthy control group and a brachial plexus injury group, and clearly shows how more severe nerve injury affects cortical functional networks and how the brain accommodates this situation. In this study, a survival animal model was used. We performed ICA on the same rats at different time points during recovery and then traced changes to the functional network.

Materials and Methods

Animal preparation: Twelve Sprague-Dawley rats (weighting 300 g) were used and equally divided into two groups. All surgeries were performed under 1.4% isoflurane anesthesia. For all rats, an incision was made longitudinally on the right chest. The subcutaneous tissues were then divided to the level of the middle portion of the pectoralis major. The brachial plexus was then identified at the level of the terminal branches. As a nerve bundle, the brachial plexus originates from C5, C6, C7, C8, and T1 nerve roots. For all animals in the healthy control group, these five nerve roots were dissected. For rats in the nerve injury group, these five nerve roots were avulsed from the spinal cord at the level proximal to the dorsal ganglia. After bleeding stopped, the incision was closed. The rats were then transferred into a Bruker 9.4 T/30 cm animal scanner. A subcutaneous infusion of Dexdomitor (0.1 mg/kg/hr) was administrated as isoflurane was tapered off. All physiological parameters were monitored including heart rate, temperature, respiration rate, and pulse oximetry. Rats were maintained in a steady state during the scan session. After the scan, all rats were recovered and put back in their cages. A special mark was given to each rat for further individual analysis over different time points. Figure 1 shows the avulsed brachial plexus of a rat in the nerve injury group. This nerve avulsion injury destroyed the sensorimotor function of the right upper limb. **fMRI parameters and data analysis:** MRI data were acquired using a gradient-echo echo-planar imaging (EPI) sequence (parameters included: FOV = 3.5 cm, TR = 2 s, TE = 18 ms, matrix size = 128 x 128, slice thickness 0.5 mm, slice number = 10, 110 repetitions). Each rat was scanned twice for resting-state data. All data were pooled and registered to ideal anatomy. The data were then averaged, and the signal outside the brain was removed. A band-pass filter was used for data with a low-pass of 0.1 Hz and a high-pass of 0.01 Hz. MELODIC was used to perform group ICA without smoothing. The total number of independent components is decided automatically.

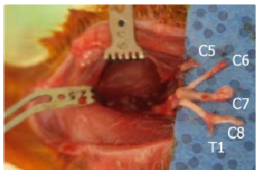

Figure 1. Photo of root avulsion injury of the right brachial plexus. C: Cervical nerve. T: Thoracic nerve.

Results

Figure 2 shows a thresholded ICA map with two slices each from the healthy control group and the nerve root avulsion injury group at $p < 0.5$. Figure 2A shows results from the healthy control group. In both slices, the somatosensory network is shown in both hemispheres. The major characteristic of this network is the symmetrical presentation of activation between hemispheres. Figure 2B shows results from the right brachial plexus avulsion group. The somatosensory network on the healthy side of the brain (which is on the contralateral side of the nerve root) remains activated. The activation pattern is highly comparable to the pattern seen in the healthy control. On the experimental side, this network is disrupted. Some of the original network disappeared, and other parts of the network were transformed from positive to negative correlation compared to the healthy side.

Figures 2C and D are the power spectra of Figures 2A and B. As an independent factor, the more severe brachial plexus avulsion injury alters the power spectrum, but the robust and sensitive frequency bands for both groups are between 0.01 and 0.05 Hz.

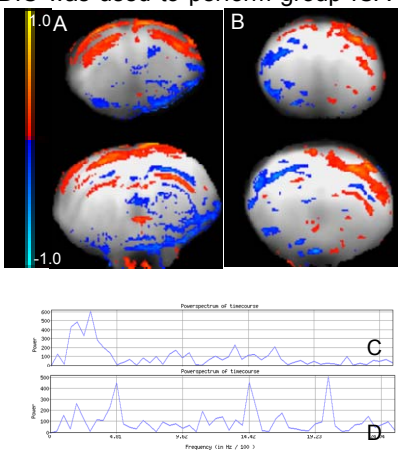

Figure 2. Thresholded ICA map of two slices on averaged resting-state dataset at $p < 0.5$. A: Somatosensory network in healthy rats. B: Somatosensory network in right brachial plexus avulsion rats. Note the symmetrical network in the healthy subjects and the breakdown of the network in the experimental group. Negative correlation was observed in B. C: Power spectrum of A. D: Power spectrum of B. For both groups, the sensitive band frequency is between 0.01 and 0.05 Hz.

Conclusion and Discussion

From this study, we have demonstrated that ICA can show the somatosensory network in rats. Similar to results found using the seed-voxel technique, this network is symmetrical across the S1 area in healthy animals. Following brachial plexus avulsion injury, this activation pattern was disrupted on the experimental side. The somatosensory network switched from a synergic functional network to an anti-correlated network, which, we believe, is related to inhibitory neuronal activity. It has been proven by electrophysiology studies that breakdown of nerve circuitry can lead to the breakdown of the functional network in the brain and in the acute stage. In this stage, the balance of inhibition and excitation within the network is destroyed, and inhibition becomes the dominant neuronal activity. We believe this accounts for negative correlation that appears in the somatosensory network of Figure 2B. More work will be completed in the coming weeks on the same groups of animals, and ICA will be used to trace the natural progression of the injury and the effects of nerve repair.