Altered BOLD Hemodynamic Response in Patients with Ischemic Stroke

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Introduction

Blood oxygen level dependent (BOLD) functional magnetic resonance imaging (FMRI) is increasingly being used to monitor recovery of brain function after stroke [1]. Most studies in stroke FMRI simply apply the principles of BOLD FMRI of normal subjects to stroke patient populations. Ischemic stroke is associated with impairment of cerebral hemodynamics, which leads to alterations in cerebral blood flow, blood volume, oxygen metabolism and vasoreactivity [2,3,4], all quantities that influence the BOLD response [5]. Primary auditory cortex can be activated by externally controlled stimulus paradigms. In this study, differences between the hemodynamic responses (HDRs) in the infarcted hemisphere and the intact hemisphere auditory cortex of patients with ischemic stroke were examined, and characteristics of the HDR of normal controls and stroke patients were compared.

Methods

Six normal control subjects, ages 50-70 yrs (2M; 4F), and 5 chronic non-fluent aphasia patients, ages 50-70 yrs (3M; 2F), with left hemisphere stroke were scanned on a 3T GE LX scanner. Scanning parameters: 1-shot spiral gradient echo sequence; 32 4-4.5 mm sagittal slices covering the whole brain, TR/TE/FA= 1660ms/18ms/70°, 3mm x 3mm in-plane resolution, five 111-image runs for the normal subjects and five 161-image runs for the patients. High-resolution anatomic images were obtained using a *T1*-weighted spoiled GRASS sequence (TR/TE/FA= 23ms/6ms/25°; 124 slices; 0.9mm x 0.9mm x 1.3mm resolution). Foam padding was provided to minimize head motion. Written informed consent was obtained for all the subjects. The patients were asked to overtly generate single word responses to a series of semantic category cues. The inter-stimulus interval was varied pseudo-randomly between 24.9, 26.6, 28.2 or 29.8 sec for patients and 16.6, 18.3, 19.9 or 21.6 sec for controls. A total of 45 semantic category cues were presented auditorily.

Data Analysis

The time courses for the 5 runs were concatenated and for each voxel, the observed FMRI intensity time-series was modeled as the convolution of the experimental auditory cue stimulus vector and the best-fit fifteen-lag impulse response. The co-efficient of determination, R^2 and F-statistic were used to assess brain activation. Images were transformed to Talairach coordinate space and voxel hemodynamic responses (HDRs) above the activation threshold, $R^2 > 0.2$ (p-value < 10^{-7}) for patients and $R^2 > 0.3$ (p-value < 10^{-7}) for controls, within left and right Brodmann area (BA) 42 (primary auditory cortex) were extracted and averaged. The full width at half maximum (FWHM), the time-to-peak (TTP) and the amplitude of the responses were calculated after fitting them to regularized generic hemodynamic responses (from *AFNI*) with a non-linear large-scale least-squares optimization method. The ischemic lesion volumes as well as gray matter volumes in a 5 mm radius around the center of mass of BA 42 activation were measured for all the patients.

Results and Discussion

Figure 1 shows a bar plot of the difference in FWHM between stroke (left) and intact (right) hemisphere BA 42 HDRs for 5 ischemic stroke patients (P1-P5, red) and between the left and right BA 42 HDRs of 6 control subjects (C1-C6, blue). The inter-hemispheric difference of the auditory cortex FWHMs among the *controls* was not significant (paired t-test $p > 0.3$), whereas in the patients the BA 42 FWHMs of the stroke hemisphere responses were significantly higher than the intact hemisphere BA 42 FWHMs (paired t-test $p < 0.02$). Figure 2 shows a scatter-plot of the FWHMs of the left and right BA42 HDRs for the patients and controls. A clear demarcation is seen among the FWHMs of the left and right BA 42 of the patients and between the patients and the controls. There was no significant difference between the TTPs and the amplitudes of HDRs (all paired t-tests $p > 0.2$) in stroke (left) hemisphere BA 42 and the intact (right) hemisphere BA 42. The inter-hemispheric differences in the FWHMs of the BOLD HDRs seemed to be related to the volume of the ischemic lesions, in that the larger differences in FWHM corresponded to higher lesion volumes (GLR $p < 0.009$), but unrelated to differences in gray matter volumes (GLR $p > 0.8$).

Possible explanations of the above observations include impairment of vasoconstrictory capacity [4], in the infarcted hemisphere, decreased oxygen metabolism [5] in the stroke hemisphere BA 42, or a combination of both events, which may leading to a longer fall-to-baseline time, while keeping the TTP of the BOLD HDR similar to that of the intact hemisphere.

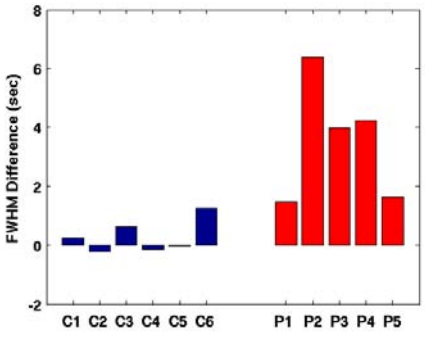

Figure.1 Bar plots of the inter-hemispheric difference of the FWHM of averaged HDR of activated voxels in BA 42 for controls (C1-C6; blue) and stroke patients (P1-P5; red).

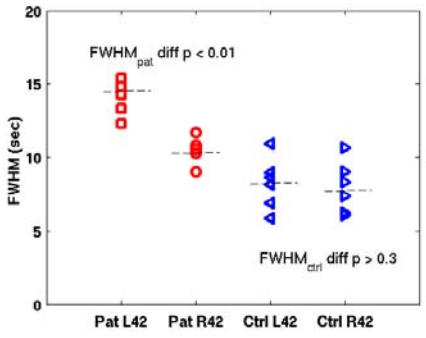

Figure.2 Scatter plots of the FWHM of averaged HDR of activated voxels in left (squares) and right (circles) BA 42 of the stroke patients and the left (left triangle) and right (right triangle) BA 42 of controls. Dotted lines denote the mean of each group.

References 1) Crosson B., et al., *J Cog. Neurosci*,**17**:392, 2005. 2) Derdeyn C., et al., *Neurology*,**53**:103, 1999. 3) Vorstrup S., et al., *Acta Neur Scan*, 74:439, 1986. 4) Kuroda S., et al., *J Nuc Med*, 45:943, 2004. 5) Buxton R., et al., Neuroimage, **23**:S220, 2004.

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