Brain deactivation during attention-demanding tasks: inhibition or blood flow compensation

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INTRODUCTION: fMRI studies[1-2] suggest that brain deactivation (negative BOLD signals) could represent inhibition mechanisms, to minimize potentially distracting, task-irrelevant neural processes. However, fMRI deactivation may also represent a compensatory hemodynamic process ("blood stealing") in the vascular system in response to changes in regional cerebral blood flow.

METHODS: Twenty-two healthy, non-smoking, right-handed subjects (10 men and 12 women, age: 30±8 years, education: 16±2 years) participated in the study. All subjects performed two sets of tasks with different levels of difficulty: a) mental tracking of multiple targets (2, 3, or 4 balls) amongst 10 moving balls (visual attention; VA)[1], and b) recognition of 0-, 1-, and 2-back targets in a sequential-letter paradigm (working memory; WM)[2]. After a training session outside of the scanner, subjects underwent functional MRI in a 4 T MRI scanner, using a single-shot gradient-echo EPI sequence (TE/TR 25/3000, 4 mm slice thickness, 1 mm gap, 33 coronal slices, 48x64 matrix size, 20 cm FOV, 200kHz bandwidth, 84 (WM) and 124 (VA) time points). Task performance and subject motion were monitored in real-time during fMRI, to assure accuracy > 80% and motion < 1mm-translations and < 1°-rotations (Fig 1). After motion correction, spatial normalization to the Talairach frame (3x3x3 mm^3 voxel size), and spatial smoothing (8mm Gaussian), activation maps were calculated for each subject and task using SPM99 (fixed-effects analysis). Group analyses of individual BOLD maps were performed using random-effects analyses (repeated measures ANOVA). Region of interest (ROI) analyses (cubic, 27 voxels) were conducted at the cluster centers of brain activation to extract the average BOLD signal from these regions.

RESULTS: Both tasks produced load-dependent bilateral activation in the parietal, occipital, and prefrontal cortices, and the cerebellum and thalamus as reported previously[3-4]. The tasks also produced brain deactivation in the frontal [superior frontal, precentral, and anterior cingulated (ACG) gyri, paracentral lobule (PCL), and the posterior insula], temporal [middle temporal gyrus], limbic [cingulate, parahippocampal (PHG), and posterior cingulate (PCG) gyri], and occipital [precuneus] lobes. While the global activation (positive BOLD signal) was larger during VA, global deactivation was larger during WM, especially in the PCL (Fig 2). For WM tasks, increased WM-load did not change brain deactivation in any brain region. For VA tasks, however, increased VA-load produced larger deactivation in the PCL, and smaller deactivation in the PHG, PCG, precuneus, and the posterior insula. During WM tasks, increased reaction time (RT) and lower performance accuracy were associated to increased deactivation of the deactivated network (Fig 3). The negative BOLD responses during VA tasks, however, did not correlate significantly with RT or performance accuracy. The ROI analyses demonstrated that the FWHM of the negative BOLD amplitudes in the deactivated network were larger for VA than for WM, but similar for the positive BOLD amplitudes in the activated network (Fig 4). Cross-correlations in the deactivated network were higher during VA than during WM, but similar in the activated network.

CONCLUSIONS: Brain deactivation appears to occur predominantly in brain regions that potentially interfere with or are unimportant for performing the required tasks, and is probably a compensatory response to optimize task performance due to limitations in processing bandwidth. Deactivation is most likely the result of inhibitory neural processes that reduce neural processing and local delivery of oxygen and blood to the deactivated network. Therefore, our findings suggest that on visual attention-requiring tasks, deactivation is a consequence of inhibition to minimize interference of unnecessary of less germane neural processing (e.g. peripheral vision and auditory function) and maximize resources for visual attention processing.

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Fig 3

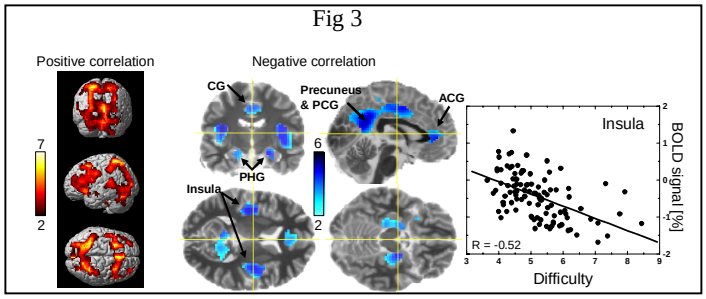

Fig 2

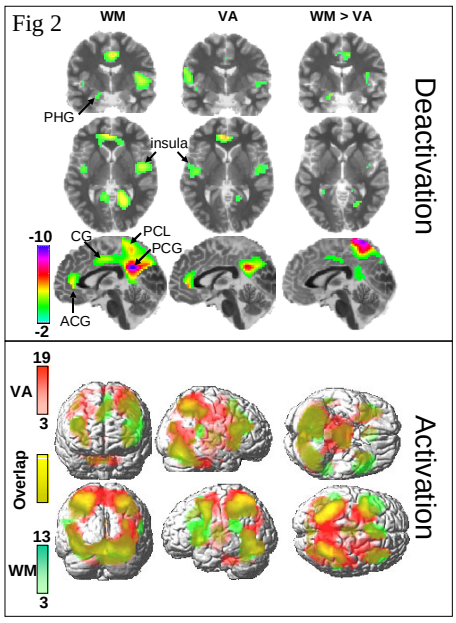

Fig 1

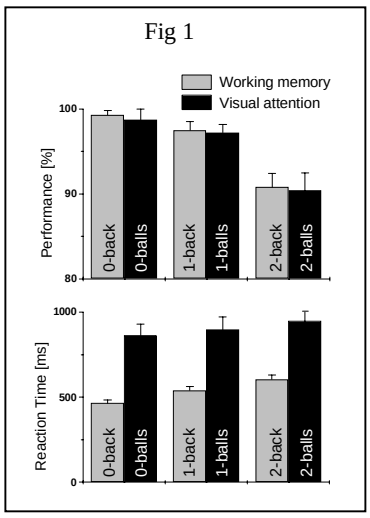

Fig 4