Correlating patterns of fMRI activation with behavior: An example from category learning.

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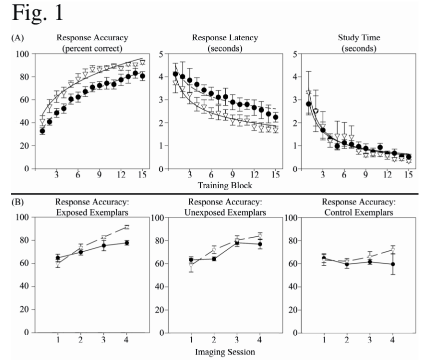
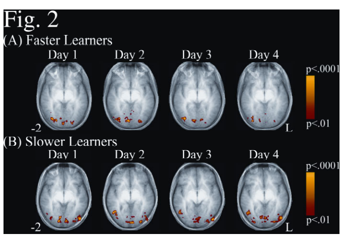
Object categorization is a basic cognitive task required for everyday survival yet the biological response that underlies category learning has only been documented in broad terms. Large individual differences are observed during the early stages of category learning in both functional MRI (fMRI) activation maps and behavioral data [1]. The current investigation characterizes this variability by correlating the volume of activation with behavioral performance.

Methods. Healthy subjects (n=17) were trained to classify patterns of random dots [2] into categories using a 4-choice categorization task with immediate visual feedback. Functional MRI was performed prior to training and then following each of 3 training sessions (4 imaging session, 3 behavioral sessions). The fMRI sessions involved the presentation of 3 paradigms which required the determination of whether two patterns of dots belonged to the same category. The paradigms differed on the type of materials presented which could either have been used in training (Exposed), not used in training but created with the same rules (Unexposed) or completely novel (Control). Imaging was conducted on a 3.0-Tesla whole body scanner (Signa VHi, GEMS) using serial gradient echo, echo-planar imaging (voxel size: $1.5x1.5x3mm3^3$). A 3D high resolution anatomical scan was also acquired (3D inversion recovery fast spoiled gradient recalled (plane = axial, TR = 9ms, TE = 2.0ms, flip angle = 25 degrees, acquisition matrix = 256x256, FOV = $22x16.5cm^2$, slice thickness/gap = 1.5/0 mm/mm, slices = 124).

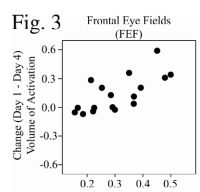
Fig. 1



Results. Rates of learning were calculated for each subject based upon a best-fit power function applied to the training data. Both behavioral and imaging data were sorted based upon these rates of learning so that differences between faster and slower learners could be evaluated. Fig. 1A (right) shows that faster learners have a higher overall rate of accuracy and a greater reduction in their response latencies over the training protocol. The slower learners showed lower accuracy and longer latencies but took no additional study time. Fig. 1B shows consistent patterns of behavioral response during image acquisition such that faster learners had a greater accuracy on the task. Importantly, neither the slower nor faster learners showed improvements in accuracy on the control task.



The imaging data presented in Fig. 2A (left) show that the faster learners show overall decreases in activation following the completion of training (Day 3 vs. Day 4). However, the opposite finding is observed for the slower learners (Fig. 2B); namely an increase in activation over the course of the experimental protocol. Faster learners demonstrate initial *increases* in volume of activation (Day 2 vs. Day 3) that are followed by *decreases* in activation (Day 3 vs. Day 4) for middle frontal gyri (MFG; $p<.05$), frontal eye fields (FEF; $p<.01$), tertiary visual cortices (V3; $p<.01$), and both inferior (IPL; $p<.01$) and superior parietal lobules (SPL; $p<.01$). The slower learners show only *increases* in the volume of activation (Day 2 to Day 3, and Day 3 to Day 4) for MFG ($p<.01$), FEF ($p<.01$), and the SPL ($p<.01$).



Because the above analysis suggests that network specialization (reduction in volume of activation) is correlated with successful learning across groups of subjects, a correlation analysis evaluating individual differences was conducted comparing the magnitude of change observed in the volumes of activation for each ROI for each subject with the rate of learning observed in the behavioral training task for each subject. The relationship between the volume of activation and rate of learning is exemplified in Fig. 3 (right) for the FEF ($r=.704$, $p=.002$), visual cortex (V1/2: $r=.543$, $p=.024$; V3: $r=.739$, $p=.001$) and for the parietal lobules (IPL: $r=.573$, $p=.016$).

Conclusion. The present data support the observation that at least two stages underlie category learning. The first, recruitment of nearby tissue, is observed as initial increases in the volumes of activation. These initial stages of recruitment are followed by specialization across the same network which is observed as reductions in activation with continued improvements in behavioral performance.

References

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