Brain Areas Specific for Attentional Load in a Motion Tracking Task

Jorge Jovicich[1,2], Robert J. Peters[1], Christof Koch[1], Jochen Braun[1], Linda Chang[2], Thomas Ernst[3]

Computation and Neuronal Systems[1], Caltech, Pasadena, California, Departments of Neurology[2] and Radiology[3], UCLA School of Medicine, Harbor-UCLA Medical Center, Torrance, California

INTRODUCTION: The aim of this study was to investigate the neural basis for attentional load effects in humans. Although recent neuroimaging studies (1,2,3) suggest the involvement of parietal cortex, MT/V5 complex and prefrontal cortex in the regulation of visual attention of moving targets, the relationship between activity in these areas and attentional load is still undetermined. Here we use fMRI to measure brain activity in humans as they covertly track a variable number of moving targets in a parametric design study. This design allowed us to distinguish between non-specific attention (zero order) effects from specific attentional load (first order) effects.

METHODS:

Subjects and stimuli: Four healthy subjects (2 male, age 24±2 years) with normal vision were investigated. A ball-tracking paradigm was used to evaluate brain responses to different visual attentional loads. At the beginning of each epoch, subjects saw a 2s text cue (TRACK or PASSIVE) followed by a 2s period during which they saw motionless balls, those to be tracked being highlighted. After this, the balls started moving in random directions and the highlighting disappeared (all balls were identical and they never overlapped). Subjects had to track none (passive viewing) or two to five balls (attentive tracking) while keeping fixation. After 14s, the balls stopped moving and a single ball chosen at random was highlighted for 1s. Subjects had to give a two alternative forced choice response to indicate whether the ball was among those they were tracking or not. This gave an objective measure of tracking, with 50% being chance.

Eye tracking: After subjects were trained to accurately (>90%) track 2, 3, 4 or 5 balls, a close-up video was recorded outside the scanner to asses proper fixation. The tapes were scored, blind to the tasks, for four types of eye movements: blinks, small saccades (~1°), large saccades (>2°), and smooth pursuits.

FMRI: Whole brain single shot T_2*-weighted spiral functional images were acquired using the manufacturer's head birdcage coil on a 1.5-Tesla scanner (General Electric Signa, Milwaukee, WI). Imaging parameters were: TE=50ms, TR=2500ms, 3.125 x 3.125 mm in plane resolution, 4mm-thick axial slices, 1mm slice gap.

Data analysis: Data were preprocessed using standard procedures in SPM99b (4). Before statistical analysis, data were motion corrected, Talairach normalized, and spatially smoothed. The data were analyzed using a fixed-effects statistical model comprising subject-specific effects. A parametric study design (5) was used to identify the form of the relationship between the experimental parameter (attentional load) and hemodynamic response. The signal from each voxel was characterized using a linear polynomial expansion of the experimental parameter and a residual error term after each component has been fitted to the data. For the box-car definition only the 14s corresponding to the ball tracking period of each epoch were considered. This eliminated the confound of different cues at the start and end of the different trials. A statistical threshold of $p<0.001$ uncorrected was used for areas for which we had prior hypothesis (V5/MT+, superior parietal lobules, anterior cingulate) and $p<0.05$ corrected elsewhere.

RESULTS: The average tracking performance during fMRI was approximately 81±15% for two to four balls and 62±5% for five balls. The eye motion recordings demonstrated that there were no smooth pursuits. Thus, tracking of the target balls must have been due to covert attentive tracking. In addition, no significant correlations were observed between any type of eye movement and the number of balls tracked. Also, no significant differences in the number of eye movements were observed between active tracking and passive viewing. Therefore, differences in brain activity between these conditions are unlikely to be due to eye movements.

When comparing attentive tracking of two to five balls (zero-order term) and passive viewing we have identical physical stimuli, therefore any differences in activity reflect internal processes, i.e., non-specific attention effects. This contrast gave significant bilateral activation in superior parietal lobules (SPL, t=16.6), transverse parietal sulcus (TransPS, t=7.4), anterior and posterior intraparietal sulcus (AntIPS, t=6.6 and PostIPS, t=6, respectively), V5/MT+ (t=8.5), and the inferior precentral sulcus (InfPreCS, t=4.1). The effect was strongest in the parietal areas and non significant in the primary visual cortex.

The first order effects modeled a linear relationship between brain responses and the number of tracked balls, so these effects are specific to attentional load. The strongest linear effects were found bilaterally in SPL (t=6.6), AntIPS (t=6.1) and TranIPS (t=6.4). Smaller but still significant linear effects were identified in locations consistent with the kinetic occipital cortex (KO, t=5), V5/MT+ (t=4.9), anterior cingulate (AC, t=4.7). All significant linear effects were positive. No significant second order effects were observed.

DISCUSSION: The observed attentional effects showed a graded response in agreement with recent results (2), with the effects being strongest in the posterior parietal areas, smaller in V5/MT+ and non significant in V1. What this study adds is the direct relationship to attentional load. We

show that neurons in SPL, AntIPS and TranIPS are specifically involved in processes that control attentional load in a visual tracking task.

References:

1. Culham, J.D., et al., J. Neurophys., 80, 2657-2670, 1998.
2. Buechel, C., et al., Brain, 121, 1281-1294, 1998.
3. Wojciulik, E., et al., Neuron, 23, 747-764, 1998.
4. Friston, K.J., et al., Hum Brain Map, 2, 189-210, 1995.
5. Buechel, C., et al., Neuroim., 8, 140-149, 1998.

Acknowledgments: We thank G. Glover for providing us with the basic spiral sequence and reconstruction algorithms, as well as G. Rees and N. Kanwisher for useful discussions and comments.