# Cortical Location of Saccadic and Vergence Oculomotor Learning Revealed using fMRI

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***Abstract*– Motor learning is critical to the survival of all species and changes throughout life via neuroplasticity. The brain receives most of its information about the external world via the visual system. Saccadic eye movements are used to quickly shift the fovea to objects on interest using conjugate movements which are typically used during reading. The vergence system uses disconjugate movements of the eyes providing depth perception. This research will compare neural activity results during predictable and nonpredictable visual conditions using functional MRI (fMRI) in humans during saccadic and vergence eye movements. There were three primary results from this research: 1) activation was observed in occipital, frontal, parietal, temporal, a cerebellar regions, 2) short-term neuroplasticity via recruitment and synchronization was observed in the cerebellar vermis 4/5 and 3) the frontal eye field and the parietal eye field had similar but also distinct areas of activity allocated for saccadic and vergence eye movements.**

## I. Introduction

Eye movements are mediated to direct the object of interest to the fovea, the area of the retina which has the highest density of photoreceptors and the corresponding largest amount of cortical area. The harmonious relationship between head and eye movements provides the required fixation of the fovea on the visual stimuli which is called gaze [1]. Saccadic and vergence eye movements are gaze-shifting mechanisms which have higher acuity and resolution characteristics for visual stimuli by utilizing the eye muscles effectively [2].

Cortical adaptation and modification in motor control for visual tasks can be evaluated as the result of two important mechanisms; motor learning and motor memory. Prediction is defined as having prior knowledge of the event. For example, when a subject knows the timing, direction, and magnitude of a visual stimulus then motor learning will occur via prediction. When a visual task is learned by a person, the latency is shortened and the peak velocity is increased when prediction can be utilized [3].

The purpose of this study is to understand how the brain is involved in the behavioral modification observed in eye movements by comparing predictable and non-predictable functional activities.

## II. Methodology

Eight young volunteers participated in this study and signed informed consent approved by UMDNJ. Subjects had normal binocular vision assessed by using the Randot Stereopsis Test and had no reported neurological dysfunction.

A custom MATLAB software program was used to create the saccadic and vergence visual stimulus. A box car protocol was utilized studying predictable and non-predictable states. Figure 1 shows the visual display for saccades where the target alternated between the left and right visual field for a known period of time for the predictable stimulus and randomly alternating between the left, center, and right visual field for the non-predictable stimulus. Vergence was stimulated using a red and green line where the subject wore red and green filter glasses so each eye only saw one target. A non-metallic screen was used to project the image. With the aid of mirrors, subjects could view the target through the bore of the magnet and were instructed to move their eyes to the target.

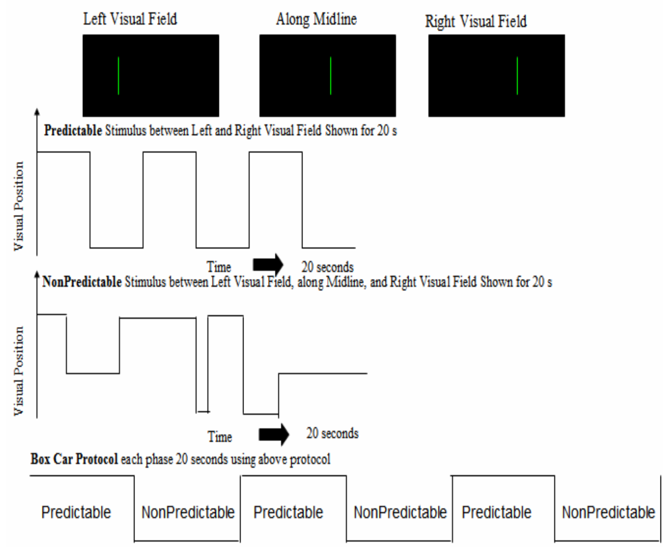


Figure 1: Saccadic visual stimuli presented to the subject

Data were collected on a 3T Siemens magnetron. High resolution axial and sagittal anatomical scans were collected. For functional imaging, the TR was 2 sec and 32 slices were collected over the entire brain with a resolution of 3.75 x 3.75 x 5 mm in the axial slice. For the stimulus, 3 cycles of "off/on" predictable versus non-predictable were collected where each state was 20 seconds or 40 seconds per cycle for a total of 120 seconds or 2 minutes. An MPRAGE scan was performed collecting 150 images of brain with a spatial resolution of 1 $mm^3$ that was needed for Talairach transformation.

Talairach transformation was performed using @auto_tlrc command which displayed the coordinates of the activated parts of the brain using the AFNI software package (Analysis of Functional Neural Imaging). Data were averaged to show areas activated in 7 out of the 8 subjects. Boolean analysis revealed commonality between experiments as well as differences. Only areas that showed a statistical significance of $p<0.001$ are shown.

## III. Results

Activation in occipital, frontal, parietal, temporal, subcortical and cerebellar regions was observed for saccades and vergence, Figure 2.

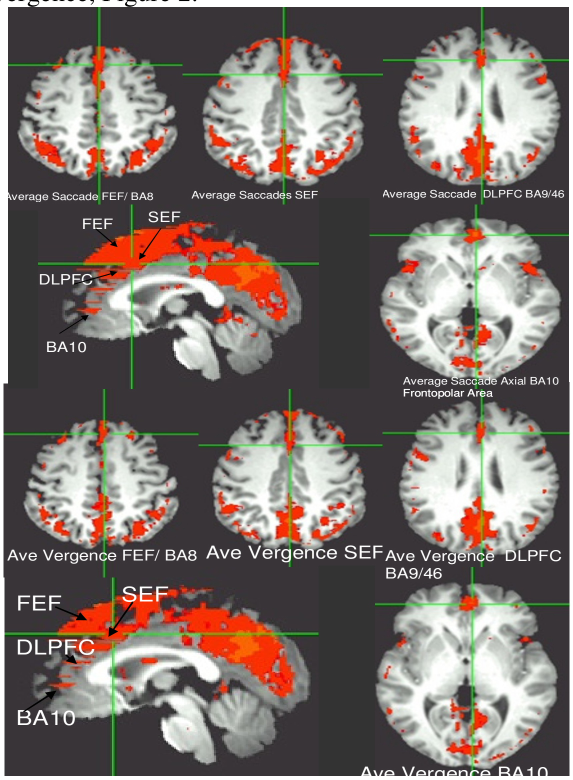


Figure 2: fMRI activity (red) during a predictive oculomotor learning experiment for saccades (upper) and vergence (lower).

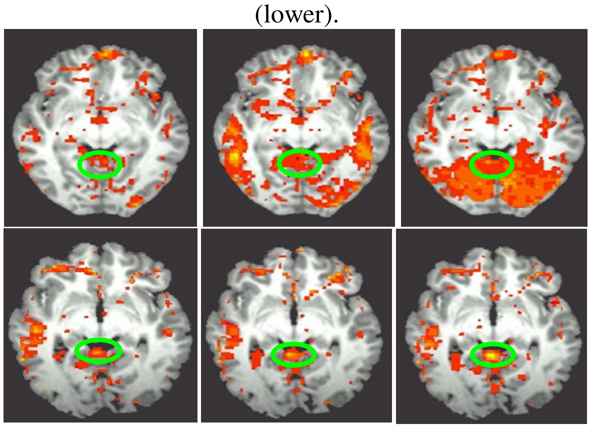

Figure 3: Types of oculomotor learning observed

Recruitment shown as an increase in activation area is observed in the upper figures across trials in Figure 3. Synchronization is observed across trials as an increase in intensity where the area becomes more yellow showing a greater correlation in the lower figures in the cerebellar vermis.

Boolean comparison of commonality and differences between saccades and vergence indicated that a distinct area within the FEF (BA8) and the PEF (BA7) was only activated for vergence.

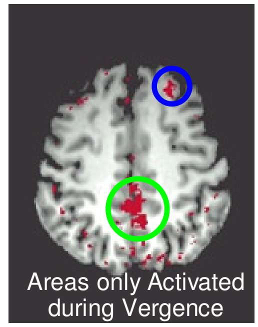


Figure 4: Regions activated only during vergence eye movements and not observed during saccadic oculomotor learning. Area circled in blue is BA 8 or the frontal eye fields (FEF) and the area circled in green is BA 7 or the parietal eye field (PEF).

## IV. Discussion

This research showed that many areas are involved in accomplishing visual tasks. The occipital lobe (BA 17, 18, 19) was activated because the visual stimuli stimulated different parts of the visual fields. Activation of the PEF (Parietal Eye Field) is speculated to be from attention and visual spatial integration. Regions of the frontal lobe such as FEF, SEF, DLPFC, BA 10 were active due to prediction and short term memory for accomplishing a given visual task. Furthermore, the cingulate eye field was active because this area is also involved in attention. The activation of basal ganglia is speculated to be related to memory. Temporal lobe activation was unexpected, but may be the result of the ventral and dorsal visual processing streams. We speculate that additional portions of the parietal eye field were activated during vergence because more attention and spatial perception was needed for the vergence task. Motor learning was observed in Cerebellar Vermis 4/5 by using synchronization and/ or recruitment. A distinct area within the FEF (BA 8) was activated only for vergence which has also been observed in single cell recordings in primates [4].

## V. Conclusion

Results show that activation between saccades and vergence was similar both within subjects and between subjects. Different types of motor learning via recruitment and synchronization were observed which varied based upon the subject. Distinct areas of activation in the frontal eye field and parietal eye field were activated only during vergence tasks.

## Acknowledgement

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