**fMRI Analysis of Retinotopy in the Visual Cortex**

**Abstract**

# This paper reanalyzes data presented in the research paper by Kay et al. titled “A temporal decomposition method for identifying venous effects in task-based fMRI” that evaluates the voxel-specific BOLD signals in fMRI that evidence retinotopy in the visual cortex. The analysis presented here is consistent with the findings by Kay et al. and previous observations, but it is largely simplified to better understand the complex processes that occur in the brain (especially the visual cortex). The analyzed data showed that there was variability in voxel activity near the visual cortex, as suggested by the standard deviation map. Moreover, the authors concluded that as the eccentricities from the fovea increased (if the visual stimuli were away from the focus spot), the corresponding BOLD signal intensity was further away from the visual cortex. In this paper, these results are suggested by the condition animation that was created which helps visualize the aforementioned phenomenon. It was found that the authors’ conclusions were consistent with the algorithm that I developed, which will be discussed in subsequent sections. Additional analysis shows that random voxels behave differently i.e., some may increase BOLD signal intensity, or some may decrease BOLD signal intensity over time. The effect of this polarity was not delved into because the voxel matrix was unimaginably huge, and it was outside the scope of the project.

# Background

# Retinotopy (also referred to as retinal mapping) is the mapping of visual information from the retina to neurons in the brain. The parts of the brain that receive visual information are segregated into visual field maps (or retinotopic maps). These maps were created using MATLAB data processing to visualize activity in the visual cortex in response to a changing stimulus.

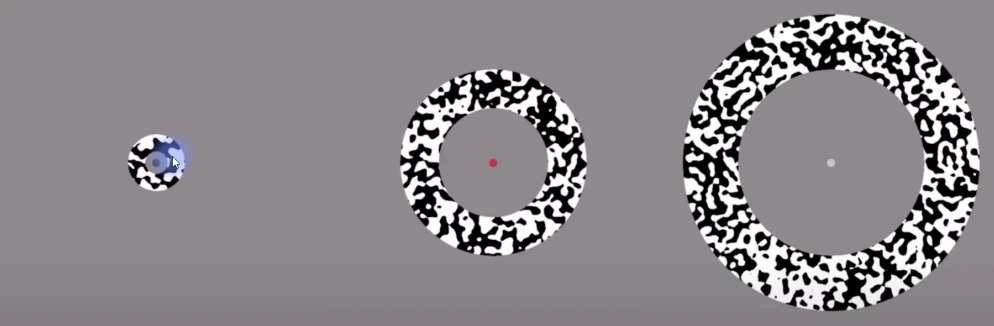
# The BOLD (Blood-oxygen-level-dependent) response is when neurons increase their spike rate or firing rate of axons. They draw on oxygen and various nutrients which can be detected by the fMRI machine, and this dictates the ‘activity’ of the neurons. The BOLD response changes over time were measured for each particular voxel (3D pixel) of the spatial flattened brain to draw plausible conclusions about the experiment.

# The eccentricity effect is a visual phenomenon that affects visual search or the processing of visual stimuli. It is believed that visual search is better – faster and more accurate – when the visual stimulus is presented closest to the fovea (focus point of retina that produces the brightest image), and evidently worsens when the visual stimulus is presented further in the periphery of the retina. The former is true because the brain activity (BOLD response) maps show activity closest to the visual cortex, the primary cortical region of the brain that receives, integrates and processes visual information incident on the retina. The MATLAB code for this project reflects this idea and helps visualize the eccentricity effect.

# Materials and Methods

All datasets used are available at the OSF site[[1]](#footnote-1). Raw data is hosted at OpenNeuro[[2]](#footnote-2), and the preprocessed data (fMRI time series data and eccentricity data used for this project) can be found at the OSF site.

In the experiment by Kat et al., research participants viewed a set of rings that had a zebra-like pattern on it (and there were six eccentricates- from the least to most eccentric). The figure below shows three out of the six eccentricity patterns that were shown to participants.



The researchers measured fMRI activity for each of the conditions or visual stimuli shown and that data is analyzed in this project.

# For this project MATLAB R2021b version was used to achieve the following:

# Visualizing flat maps of the visual cortex using fMRI voxel data and time points for averaged 4 sessions

# Creating a standard deviation map of the visual cortex to spatially see variability of signals over time

# Processing BOLD response over time for a random voxel point and finding the trendline parameters (fit parameters and goodness of fit)

# Rendering event/condition-related BOLD response graphs to distinguish the 6 visual eccentricity conditions

# Creating an animation to visualize visual cortex activity in response to the 6 conditions (visualizing BOLD response changes for each voxel and putting into perspective fit parameter data for each voxel)

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# Analysis

# The first graph in this subplot (Figure 1) represents a flat map of the cortical regions near the visual cortex of the brain and shows brain activity in different regions at time point 143. The MATLAB code Map Description automatically generatedchooses a random time point and prints the corresponding flat map because creating a plot for over 350 time points was not feasible. This graph serves to visualize the flat map in terms of voxel positions and voxel activity/ “noise”; the concavity on the left is the visual cortex of the brain. The red regions of the colormap show maximum brain activity (increase in metabolic processes i.e., transport of oxygen to that part of the brain) whereas the blue part shows minimum brain activity. No data was recorded for the areas outside the periphery of the flat map, so it shows up as blue too.

# The second graph of the subplot represents the standard deviation or brain activity variability in terms of voxels over time. The areas in red are changing the most over time – maximum changes in BOLD response. The areas in blue are changing the least over time – minimum changes in BOLD response. These two graphs help understand the data qualitatively to that the following analysis is easier to interpret. The predominant purpose of creating these maps was to visualize the huge data set.

Figure 1: Flat map at random time point and standard deviation map

# Figures 2 and 4 are graphs that shows how the BOLD signal intensity changes over time for a random voxel chosen by the MATLAB code. Again, the graph for one voxel was plotted because creating plots for each voxel (over 120,000 plots) was not feasible. Both figures 2 and 4 show a lot of fluctuation in the BOLD signal intensity over time, resulting in an r-squared value of 0.06 for voxel #27344 and 0.02 for voxel #49891. Perhaps, a linear model wasn’t the best fit for this model, but it helps visualize the general trend. Overall, BOLD signal activity for figure 2 (voxel #27344) increases with slope 0.08, whereas the BOLD signal activity for figure 4 (voxel #49891) decreases with slope -0.06.

# Fit data written into file project.dat for figure 2 is “BOLD signal intensity increases (on average) with time for voxel #27344. The fit parameters are 0.08 and 1461.32. The goodness of fit r squared value is 0.06. Note: This data is only for one particular voxel point that is chosen at random.” For figure 4, “BOLD signal intensity decreases (on average) with time for voxel #49891. The fit parameters are -0.06 and 973.32. The goodness of fit r squared value is 0.02. Note: This data is only for one particular voxel point that is chosen at random.” These two distinct graphs show that BOLD intensity activity generally increases for some voxels and generally decreases for some voxels. A commented out for loop in the MATLAB code helps figure out which voxels show an increase/decrease in BOLD signal intensity.

# A screenshot of a graph Description automatically generated with low confidence

Figure 2: BOLD time course for random voxel

# A picture containing chart Description automatically generated

Figure 3: Event 1 onsets for figure 2 graph

# Line chart Description automatically generated

Figure 4: BOLD time course for random voxel

# A picture containing chart Description automatically generated

Figure 5: Event 1 onsets for figure 4 graph

# Figures 3 and 5 show times at which Event 1 occurred i.e., when the first visual eccentricity was shown to research participants. The magenta dashed lines intersect with the BOLD signal intensity graph to show how event 1 onset affected BOLD signal intensity for that particular voxel. Since there are over 120,000 voxels, it is impossible to make conclusions from the data given above. Therefore, the animation helps visualize the phenomenon for each particular voxel. In simple terms, the data from the aforementioned graphs was used to create an animation for each event onset and decipher how these onsets effect brain activity near the visual cortex. The previous numerical analysis served to contextualize the animation and help understand how BOLD signals fluctuate over time depending on the condition/event onset.

# The flat maps below are from the animation at 6s. It is created from all the BOLD intensity change data for each voxel described before. Even though, it is difficult to quantitatively underpin what is happening near the visual cortex because of the massive data set, it can be qualitatively delineated (more about this in the Discussion). It is important to note that these qualitative discussions are based on quantitative analysis of the BOLD intensity changes for each voxel.

# A picture containing map Description automatically generated

Figure 6: Flat maps for the six conditions at time 6 s

# Note: If the animation does not work due to the MATLAB version or some unprecedented error, the animation video can be viewed by going to this link[[3]](#footnote-3).

# Discussion

# The primary researchers’ results and conclusions can be summarized in the following manner: “As the visual eccentricity was presented further away from the fovea/focus point, BOLD response activity (metabolic activity such as transport of oxygen to that part of the cortex) was further away from the visual cortex.” As seen in figure 6, this conclusion is consistent with the MATLAB code and the researchers’ findings. In figure 6, condition 1 shows maximum activity (red color represents maximum BOLD response at that time) nearest to the visual cortex because in condition 1, participants were shown visual stimuli closest to the fovea. On the contrary, condition 6 shows maximum activity further away from the visual cortex because in condition 6, participants were shown visual stimuli farthest from the fovea; this forms the basis of localization in the brain and provides evidence for the eccentricity effect.

# BOLD response activity fluctuates over time as seen in the BOLD time course graphs, but there is a pattern in their intensity when the different conditions are introduced. This quantitative aspect is visualized in figure 6 and explicated qualitatively. At the surface-level one can imagine that the most voxels nearest to the visual cortex were activated in response to the first condition, and the activity moved away from the visual cortex as the eccentricity level increased. The animation was an elegant way to visualize and interpret the massive data set to draw plausible conclusions about the research study by Kay et al. Although the researchers used complex techniques like GLM (general linear model- writing multiple linear regressions simultaneously) analysis and TDM (temporal decomposition through manifold fitting) models, a simple MATLAB code presented in this project showed that the primary results could be realized in a simpler way.

# Conclusions

# To conclude, the findings of this project are ‘superficially’ consistent with those of the primary researchers. Kay et al. used some very advanced computational neuroscience data analysis techniques that were well beyond the scope of this project. However, the overarching results or the main take away from the study was replicated by the data processing in this MATLAB project.

# In addition, this project explored random data (choosing random voxels or data points) to put the complex idea of retinotopy and eccentricity effect into perspective, drawing conclusions by combining the voxel data in all its prior randomness. BOLD intensity fluctuations over time were generalized as an increasing or decreasing trend and a standard deviation map of the cortical region concerned was created to visualize activity variability. All these data analysis techniques, combined with the ultimate animation helped achieve the objective of the project.

# Prospective studies about irregular visual stimuli (asymmetrical eccentricities) can be conducted to create retinotopic maps and further delve into the complexities of the eccentricity effect. Such endeavors might uncover relevant findings that will revolutionize the fields of neuroscience and behavioral biology.

# References

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1. # <https://osf.io/j2wsc/>

   [↑](#footnote-ref-1)
2. # <https://doi.org/10.18112/openneuro.ds002702.v1.0.1>

   [↑](#footnote-ref-2)
3. <https://livejohnshopkins-my.sharepoint.com/:v:/g/personal/agupt110_jh_edu/EQqoNLbmsXxPjsLumkMsEU0Bjd8Qw-SFLe2z0t2OBUqcZg?e=rdOdjZ> [↑](#footnote-ref-3)