Investigating Binocular Rivalry Using Quantitative fMRI

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Introduction

When two dissimilar images are independently and simultaneously presented to the two eyes, they compete for perceptual dominance so that only one image is visible at a time and the other is perceptually suppressed. The exact brain site and neural mechanism for this binocular rivalry phenomenon remain unknown. The major debate centers at the question of whether eye-specific suppression occurs in early visual areas[1] (e.g. V1 and V2) or in higher-order visual areas[2]. Recent fMRI studies reported a strong correlation between fMRI signal and eye-specific perceptual enhancement and suppression[3,4] in early visual areas of lateral geniculate nucleus (LGN) and V1. These results suggest that binocular rivalry is mediated by competitive interactions between monocular neuronal populations before the convergence of the inputs from the two eyes. If rivalry is completely resolved in monocular LGN and V1 neurons (also see ref. 5), it can be predicted that: 1) eye-specific suppression during occurrence of rivalry should lower the activities from the suppressed eye, and thus the average activities in LGN and V1 during rivalry should be smaller than those with the same input but no rivalry is involved; 2) the activity decrease should be independent of the switching frequency between the two perceived images when the signal is integrated over multiple cycles of perceptual dominance period. In this study, we have measured and quantified blood oxygenation-level dependent (BOLD) responses in V1 to four different rivalry conditions with distinct perceptual dominance periods. We compared the BOLD amplitude during rivalry when two dissimilar images were simultaneously presented the two eyes to the summation of the activities from the same monocular stimuli separately presented to the corresponding eye. A significant and consistent suppression in BOLD responses for all the rivalrous conditions was observed. The result provides further evidence supporting the notion that rivalry starts in early visual areas.

Method

The rivalrous stimuli consisted of a pair (red and blue) of superimposed sinusoidal gratings orthogonal to each other and were presented with an annulus centered at the fixation point. When these were viewed through a red filter glass by one eye and through a blue filter glass by the other eye, only one grating is visible to one eye and the other is visible to the other eye. These orthogonal gratings were presented in manners of a) fast rotating, b) slow rotating, c) being static, and d) simultaneously moving horizontally (red gratings) and vertically (blue gratings). These four different stimuli all yielded effective rivalry with different average perceptual dominance periods which were measured in a separate behavior study.

All fMRI studies were performed on a 4T/90 cm bore magnet (Oxford, UK) system with the Varian INOVA console (Varian Inc., Palo Alto, CA). For the fMRI experiment: GE EPI (FOV = 20×20 cm^2; 64×64 image matrix size; TE = 47 ms; TR = 1 s, 7 coronal slices, 5 mm thickness) covering most of the calcarine fissure were acquired. The fMRI experiment was conducted in a block-design manner. In each fMRI run, three task blocks (60 images each) were sandwiched by four control blocks (60 images each) when subjects were in uniform darkness. In each task period, subjects were in one of the following three conditions: 1) red gratings presented to right eye only, 2) blue gratings presented to left eye only, and 3) superimposed red and blue gratings orthogonal to each other simultaneously presented to either eye (i.e. rivalrous condition). All three conditions belonged to the same rivalrous category (e.g. fast rotating red gratings, fast rotating green gratings and orthogonal fast co-rotating red and green gratings) and were randomly presented in three task blocks, respectively, to avoid habituation effect. Each rivalrous category was acquired twice, which gave in total eight runs for every study.

The fMRI maps were generated by the period cross correlation (CC) method. The voxels located at the proximity of calcarine fissure were included in the region of interest (ROI) and the time course for each task was averaged from the activated ROI voxels with CC > 0.4. The BOLD percentage change was calculated from the time course for each condition. Relative BOLD response for each of the four rivalrous conditions was calculated by dividing the BOLD response at the rivalrous condition by the summation of BOLD responses to the corresponding left-eye only and right-eye only stimuli.

Results

The average perceptual dominance period for each of the rivalrous conditions mentioned above is 10.1s, 4.2s, 2.7s and 2.2s, respectively (n = 13) as shown in Fig. 1 (bars indicate standard deviation). One-way ANOVA comparison indicates there is a significant difference in perceptual dominance period among all the rivalrous conditions ($p < 10^{-5}$, $n = 13$). Fig. 2 shows the normalized BOLD amplitudes for the four rivalrous conditions. When this relative BOLD amplitude is close to one, it suggests that the two eye inputs do not interfere with each other in V1, whereas when it is close to 0.5, it indicates that one of the two inputs is completely suppressed during rivalry. The normalized BOLD amplitudes for the rivalrous conditions of moving gratings, static gratings, slow rotating gratings, and fast rotating gratings are 0.74, 0.65, 0.78, and 0.72 (n = 7), respectively. Statistically there is no significant difference among the four conditions ($p = 0.1$, $n = 7$, one-way ANOVA).

Discussion and Conclusion

If rivalry is completely resolved in early visual areas, the inputs from the two eyes would compete for perceptual dominance before the convergence of the visual information. In that situation, the activities of the two monocular populations would interfere with each other and result in lowering the average brain activity in V1 compared to the summation of the activities from two separate monocular inputs when rivalry does not occur. Our observation confirms that the BOLD activity is significantly suppressed in V1 during rivalry. Since the fMRI signal is integrated over multiple cycles of perceptual dominance periods, the suppression in BOLD should be independent of rivalrous perceptual dominance periods. This prediction is also verified in our study. Together, our results provide further evidence supporting the notion that rivalry starts in early visual areas.

Acknowledgements NIH RO1 grants of EB00329, NS41262, NS39043, EB00513 and P41 RR08079, and the MIND institute.

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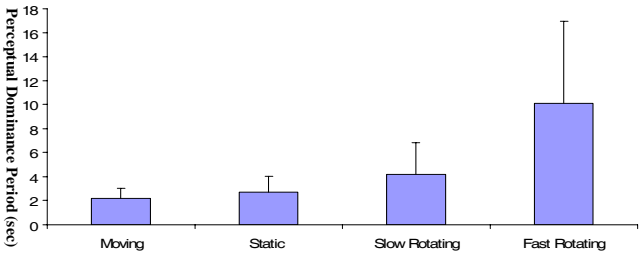

Fig. 1. Average perceptual dominance period of four different rivalrous conditions

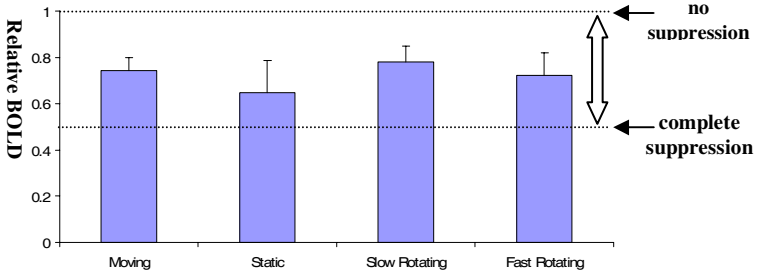

Fig. 2. Relative BOLD amplitudes (calibrated by dividing the absolute BOLD amplitude during rivalry by the summation of BOLD amplitudes at two separate monocular stimuli) in different rivalrous conditions