How Areas of Ventral Visual Stream Interact When We Memorize Color and Shape Information

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Abstract. We studied the role of ventral visual cortex areas in processing color and shape information during memorizing these characteristics. The participants (22 people) were presented with blots of different colors and shapes (9 shapes, 8 colors). There were 3 experimental series in which participants had to memorize shape, color, or both characteristics at once. A control block was also conducted, in which the task was to count the number of the same color images. EEG was recorded, then the brain activity sources were localized. Also, we calculated the connectivity parameters (via Granger causality method). During memorizing colors, we found strong connections between the V3v and hV4 areas. During memorizing the shape, connection between the VO1 areas in both hemispheres was found. When both characteristics were memorized, we found connections between the V3v, hV4, and VO1 areas. In addition, connections were observed between the VO1 and VO2 areas of both hemispheres. We suggested that hV4 and VO1 areas are related to color and shape processing, respectively. In VO2 area all characteristics are integrated into a holistic image of perception.

Keywords: Ventral visual cortex · Visual working memory · Visual perception

1 Introduction

Large amounts of data suggest that various characteristics of visual stimuli are processed by the ventral part of the visual cortex. Although the areas of the brain responsible for the perception of complex objects such as faces are fairly well established, it was more difficult to localize cortex areas that process simpler visual characteristics such as the color and shape of objects. For example, there is conflicting data on the role of the hV4 area (human V4) in visual perception: some studies have found that this area is involved exclusively in the processing of color information [2] or other characteristics of stimuli [10]. Other studies show that the color and shape information is processed in other areas of the ventral visual cortex [12].

We suggest that the reason for this discrepancy is due to the peculiarities of experimental procedures. In most studies, experimental designs are made so that participants perceive stimuli passively, without performing any task. We suppose that perception is an active process that depends on the task being performed by a person at the moment.

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In our study, the participants were given a task in which they were required to select and memorize individual characteristics of visual stimuli. The aim of the study is to identify areas of the ventral visual cortex involved in processing the color and shape of stimuli.

2 Methods

2.1 Participants

We collected data on 22 participants (13 female, 9 male, age 19.6 years, SD = 1.84). All participants were healthy with no history of neurological and/or psychiatric disorders. Each participant had normal or corrected-to-normal visual acuity, and normal color vision. The experiment was considered and approved by the Research Ethics Committee of the Faculty of Psychology, Lomonosov Moscow State University.

2.2 Visual Stimuli and Experimental Design

The participants were presented with the picture of color blot for 400 ms period (there were 8 different shapes and 9 colors). The task was to memorize either the color or shape, or both characteristics together. In the control series, the same stimuli were presented, but the task was to count the number of figures with a certain color (see Fig. 1).

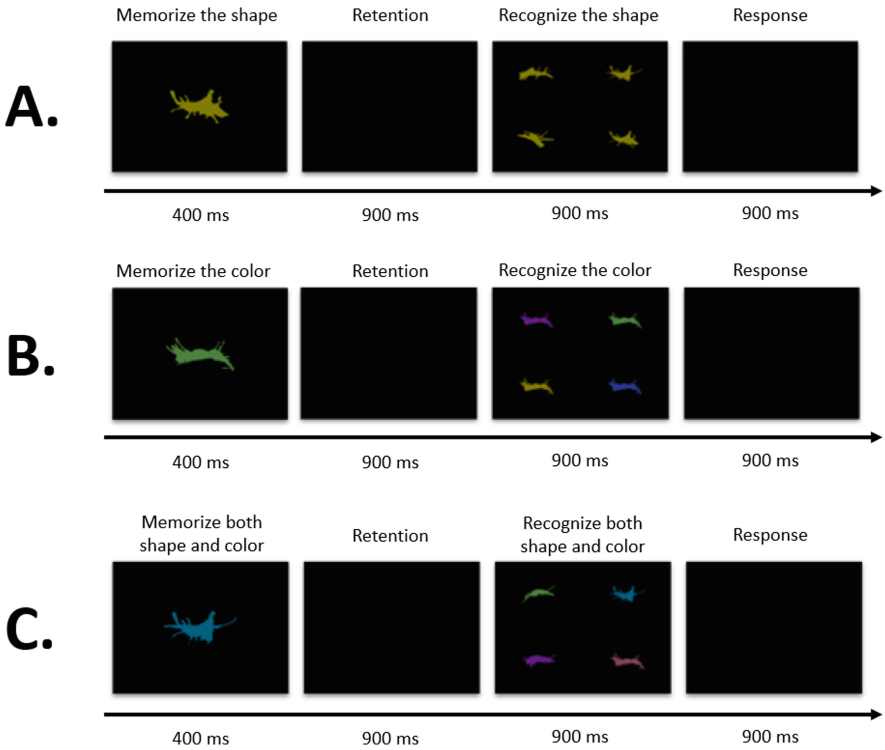

Fig. 1. Design of experiment. A – shape memorizing session, B – color memorizing session, and C – both shape and color memorizing session.

2.3 EEG Methods

EEG was recorded (19 channels, 10–20% system) and evoked potentials (ERP) were calculated for presenting an image with a figure in each of the series. Based on the results obtained, the sources of brain activity were localized via Brainstorm [11] using the dSPM algorithm [3]. For further analysis, we selected 8 areas of the ventral visual cortex: V3v (VP), hV4, VO1, and VO2 in both hemispheres. Coordinates of areas boundaries according to Wang et al. [13] were adapted for Brainstorm. Using the Granger causality estimation method [9], causal connections between these areas of the ventral visual cortex were calculated.

3 Results

We obtained causal connections between 8 areas of the visual cortex: V3v, hV4, VO1 and VO2 in both hemispheres (see Fig. 2).

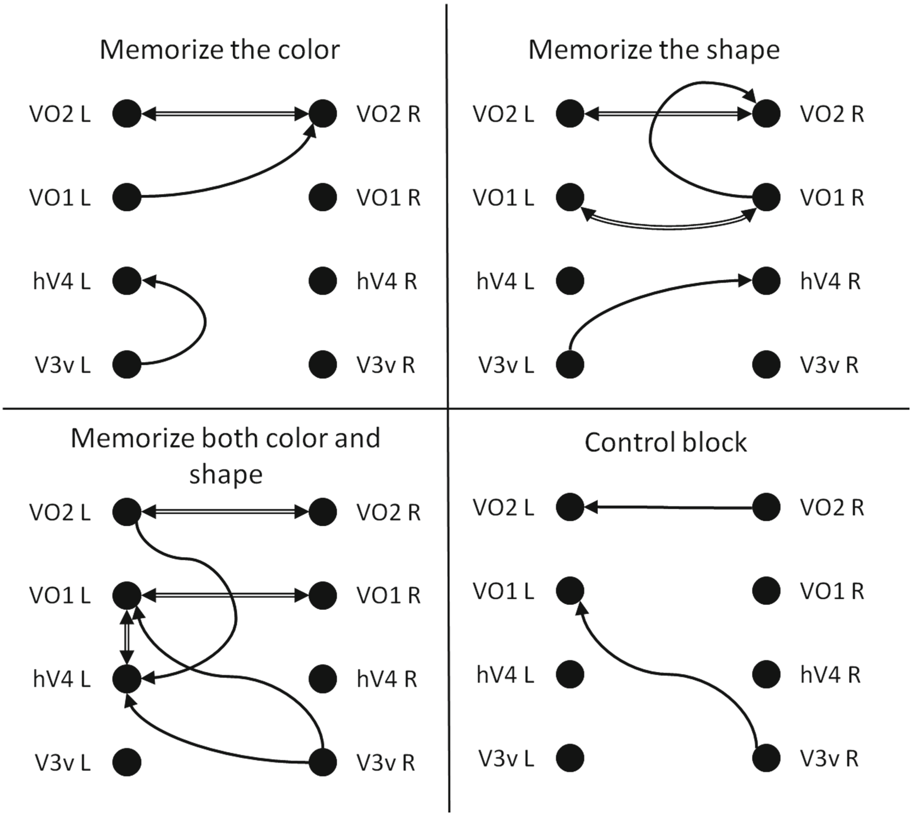

Fig. 2. Granger causal connections between the areas of ventral visual cortex for experimental sessions and the control block. "L" and "R" mean "left" and "right", respectively. The line with one arrow indicates unidirectional connections, double line with two arrows – bidirectional connections.

In the control block we found connections between V3v (right hemisphere) and VO1 (left hemisphere), and unidirectional connection between VO2 areas.

The color memorizing session shows bidirectional connections between VO2 areas, and unidirectional ones between V3v and hV4 (left), VO1 (left) and VO2 (right) areas.

In the shape memorizing session, there are unidirectional connections between V3v (left) and hV4 (right), VO1 and VO2 (right) areas, and bidirectional connections between VO1 and VO2 areas in both hemispheres.

When participants were to memorize both characteristics were, we found an integrative pattern of activation. There are bidirectional connections between VO1 and VO2 (left and right), hV4 and VO1 (left) areas, and unidirectional ones between V3v (right) and hV4 and VO1 (left) areas.

We can distinguish several patterns of causal connections. Memorizing color information requires connections between V3v, hV4 and VO1 areas; shape information—between V3v, VO1 and VO2 areas. Memorizing both visual characteristics involves all these activity patterns.

We found that visual information comes from V3v area to hV4 and VO1 areas in each experimental series, because the stimulus has color and shape characteristics. If the task is "to memorize the color", participants will switch attention from the whole stimulus to its color. That leads to increasing the level of hV4 activation and the level of connections with other areas. Under other conditions we can observe the same patterns.

4 Discussion

In a series in which participants had to memorize the color shade of stimuli (both separately and in combination with the shape), the activation of hV4 area was observed immediately after the activation of the V3v (VP) area. Human fMRI experiments have shown that V3v area neurons respond to chromatic stimuli [7]. Recently, it was proved that V4 area neurons (in primates) form a "hue preference map" [5]. It can be assumed that the human V4 (hV4) performs a similar function and integrates the color information received from V3v area.

When participants had to memorize the shape of stimuli, there were revealed strong connections between VO1 areas of both hemispheres. We suggest that connection can be associated with shape information processing. We assume that these visual cortex areas integrate information about the shape of the stimulus from both semifields of the visual field. In support of this assumption, the activity of V3v is also observed in the perception of illusory contours [6] and contours of geometric shapes [8].

We revealed that in a series in which both color and shape were required to be memorized, bidirectional connections between hV4 and VO1 were found. This data is well explained by hypothesis that hV4 is responsible for integrating information about color, and VO1 integrates information about shape of the stimuli. It is likely that when these two characteristics are processing, there is an interaction between these areas.

Finally, both the experimental and control series show activation of VO2 areas in both hemispheres. There are unidirectional (in control series) and bidirectional (in all other series) connections between these areas. In the literature there is a little amount of data which allows us to establish a functional role of these areas, and the available data is quite contradictory. Thus, according to the hypothesis of Goddard and Mullen [4], neurons in the VO2 are responsible for separating color from achromatic contrast in these areas. Wang et al. [14] suggest that this area of the ventral visual cortex has large fields of attention modulation for face and house images. It can be cautiously assumed that VO2 is rather related to the perception of stimuli as complete familiar objects. Thus, our experimental design with ERP, as well as the experimental designs described in the literature, where similar VO2 activation was observed, suggest multiple presentations of similar stimuli. Accordingly, bidirectional connections between these areas of two hemispheres may indicate the integration of information from both semifields, which is necessary for object recognition. In addition, this assumption is indirectly supported by the close connection of the VO2 area with the parahippocampal cortex, which plays an important role in the recognition process [1].

5 Conclusion

Our study clarifies the role of ventral visual cortex in color and shape perception of objects. We assume that the hV4 area is related to the integration of color information, and the VO1 area is related to the integration of information about the shape of objects. In addition, the activity of the VO2 area is probably associated with the formation of a holistic image of perception that combines all the important characteristics of the stimulus for the observer.

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