WORKING MEMORY IN COLOR: AN fMRI STUDY

N.Osakar[1]*, T.Ikeda[2],M.Osaka[2]

[1] *Department of Psychology, Kyoto University, Japan*
[2] *Department of Psychology, Osaka University, Japan*

*Corresponding author: Corresponding authors Naoyuki Osaka, +81753323418, nosaka@bun.kyoto-u.ac.jp

Keywords: working memory, color, Stroop effect, color perception, word recognition

ABSTRACT

Verbal names of colors used in daily life are essentially categorical in nature rather than a reference to the particular color of the object. Colors that cross the borders of color hue categories could be verbally coded, whereas colors within a single color category are likely difficult to be verbally coded due to the involvement of slight hue differences. A brain imaging study focused on colors in working memory in a domain-dependent dissociable brain has not been well known. Current study investigated the specific dissociated brain areas responsible for color memory under both verbal and visual coding, using functional magnetic resonance imaging (fMRI). Using n-back working memory paradigm, we hypothesized that colors that cross different categories would activate phonological loop more easily because colors having large hue differences could be more easily coded verbally, as in the case of color words, than colors within the same category with slight hue differences in which memory for adjacent colors could not rely on phonological loop. We found left- and right-frontoparietal network activations under cross-color/color-word conditions, and within condition, respectively.

INTRODUCTION

Working memory is a limited capacity system that temporarily retains and manipulates information and working memory involves two domain-specific subsystems: the phonological loop (PL) that is responsible for language processing involving color names, and the visuospatial sketchpad that is responsible for visuospatial processing involving perceptual colors [1-3]. On the basis of current neuroimaging studies on working memory, phonological loop is thought to be localized in the inferior parietal region in the left hemisphere in connection with Broca's area in the inferior frontal gyrus (IFG), whereas visuospatial sketchpad is known to be located in the right hemisphere as visual working memory. When the observer asked to decide two color patches, whether current patch is the same or different as compared with patch presented n-trial back to the current one. The observer has to retrieve (remember) the color shown in n-back before and compare it with current color using visual color working memory. As *n* increases the observer has to maintain color information longer time, thus need use of efficient coding strategy.

We hypothesized that colors that cross different color categories would activate phonological loop (verbal coding of color names) more easily because colors having large hue differences could be more easily coded verbally, as in the case of color words [4]. While, colors within the same category with slight hue differences in which memory for adjacent colors could not rely on phonological loop could be perceptually coded (not in the phonological loop but in visuospatial sketchpad region of the brain). Our assumption is that color coding in the brain's working memory could be divided into dual system. One is specific to colors that could be easily coded in verbal domain because of their large color difference The other is specific to colors that is difficult to code verbally because of their small color difference (no unique category names due to subtle difference).

METHOD

Procedure

We used n-back working memory reporting procedure which asked the observer to compare current color and that of n-back presented before. We used a block design in this fMRI study. Nine stimuli was presented on the screen in (36.5 s. Each stimulus was presented for 0.5 s followed by a 4 s interstimulus interval. Participants (n=9) asked to press a key with the left/ right thumb as instructed. A single block had a color group consisting of three stimuli, from which one was selected as the specified color (red, yellow, green or blue). Under the cross-condition, the stimuli were presented as a colored square of a specified color along with two typical colors of adjacent hue categories (e.g. red group: purple, red and orange), whereas under the within-condition, the stimuli were a specified color along with two adjacent colors in the same category to minimize possible verbal labeling. Under the word-condition, stimuli were color names printed in Japanese.

Materials

Stimuli for the color-word condition are specified with color names (e.g., red, orange, purple…) and stimuli for the cross/within-color conditions are presented with corresponding perceptual colors (the size of the background was 15 x 11 deg and the color stimulus was 2 x 2 deg). Averaged color differences (DEuv*) were 46 in the Cross condition and19 in the Within condition.

fMRI data acquisition and analysis

Whole brain imaging data were acquired on a 1.5-T fMRI scanner using a head coil. Head motion was minimized with a forehead strap. For functional imaging, we used a gradient-echo echo-planer imaging sequence with the following parameters(TR. 2.5 s, TE. 49 ms, flip angle. 801, 6mm slice thickness,FOV. 256mm_256mm, and pixel matrix. 64 x 64). We employed SPM2 software. All functional images were realigned to correct for head movement, which were less than 1mm within runs. The functional images were normalized and spatially smoothed with an isotropic Gaussian filter). Data were modeled using a box-car regressor corresponding to a single block convolved with HRF. Group data were analyzed using a random effects model. We specified activation areas of all conditions at the threshold Po0.05, corrected for multiple comparisons (false discovery rate, FDR).

RESULTS and DISCUSSION

The data were analyzed in one-way repeated measures analysis of variance and we found no main effect which indicates the performances among three conditions were mostly the same. Regarding activated brain areas, we found bilateral inferior frontal gyrus (IFG) , premotor(PM) , supplementary motor area (SMA), left inferior parietal lobule (IPL), and right intraparietal sulcus (IPS). We also calculated the percentages of signal change in each region of interest across the three conditions. On the basis of analysis of the interaction, significant difference among the three conditions were found in the bilateral IFG, left PM, left IPL, and right IPS ($p<0.05$). In Addition, we found that the left hemisphere was strongly activated under the word-condition whereas the right hemisphere under the within-condition. Under the cross-condition, the signal intensity was intermediate between the word- and the within-condition. Under the word-condition, we found

Oral paper

activation in the left IFG–IPL, which suggests that PL is possibly employed when memorizing colors. Considerable evidence of PL from neuroimaging studies and neurological patients has suggested that IPL, specifically the left supramarginal gyrus, subserving as a passive storage buffer, and frontal areas such as IFG and PM comprise the active rehearsal circuit, which is known to be

involved in the preparation of active subvocal rehearsal.The right IFG activation uniquely observed under the within-condition might plausibly be considered recruitment of that area, instead of a verbal strategy in the left IFG, to retrieve visual colors under the within condition. On comparison of the cross-condition to the within-condition, memorizing colors across several categories strongly employed the left IFG and the left IPL, respectively. This suggests that an implicit verbal strategy was very effective when executing the 2-back task under the cross-condition. Colors within the same category, however, activated the right IFG instead of the left IFG and the left IPL, indicating that a visual strategy is more useful than a verbal strategy to achieve a good performance under the within-condition

REFERENCES

1. Bornstein MH. (1976). Name codes and color memory. *American Journal of Psychology*, 89,269–279.

2. Roberson D, Davidoff J. (2000). The categorical perception of colors and facial expressions: the effect of verbal interference. *Memory and Cognition*, 28,977–986.

3. Berlin B, Kay P. (1969). *Basic color terms: their universality and evolution*. Berkeley: University of California Press.

4. Baddeley A. (200). Working memory: looking back and looking forward. Nature Review Neurosciences, 4,829–839.

ACKNOWLEDGEMENT

Supported by the JSPS Grant-S#2222003 to NO.