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GRAPHEME-COLOR SYNESTHESIA INTERFERES WITH COLOR PERCEPTION IN A STANDARD STROOP TASK

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Abstract—This study examined the proposed automatic and involuntary nature of synesthetic experiences in grapheme-color synesthetes by comparing behavioral and blood-oxygen level dependent (BOLD) responses in a synesthetic and a standard version of the Stroop task. Clear interference effects in terms of slower reaction times and stronger BOLD responses in the rostral cingulate zone (RCZ) were found in synesthetes performing the synesthetic version of the Stroop task. Surprisingly, less interference was found in synesthetes compared with controls performing the standard Stroop task. This smaller interference effect, expressed as the difference in reaction time between incongruent and neutral stimuli, was explained in terms of experienced interference during the neutral condition of the Stroop task in synesthetes. This was confirmed by stronger BOLD responses in the RCZ for synesthetes specifically in the neutral condition. To the best of our knowledge, this is the first study to show different performance of synesthetes in a standard Stroop task and the presented data can be seen as strong evidence for the automatic and involuntary nature of synesthetic experiences.

Key words: grapheme-color synesthesia, Stroop, anterior cingulate cortex, fMRI, interference.

INTRODUCTION

Grapheme-color synesthesia is a condition in which seeing graphemes elicits the experience of colors. It is a relatively rare condition and the prevalence is estimated to be 1.0–1.3% (Simner et al., 2006, 2009). An important question is whether synesthetic experiences are under voluntary control and how synesthetic experiences interact with sensory experiences. Recent studies suggest that an important proportion of synesthetic experiences is automatic and involuntary (Mills et al., 1999; Dixon et al., 2000; Mattingley et al., 2001; Hubbard et al., 2005; Weiss et al., 2005). Evidence for this can for instance be found in studies that used Stroop-like tasks and tested whether task irrelevant synesthetic experiences influenced performance and brain activation. In a standard Stroop task (Stroop, 1935) participants have to name the color of color words printed in the same or different color. Interference is caused by a color word printed in an incongruent color, leading to slower reactions and more errors as compared to color words printed in the congruent color and neutral words not printed in a color. This interference effect indicates that it is impossible to fully ignore the task-irrelevant aspect of the task, i.e. reading the color word, and that the reading process seems to be automatic and involuntary. Recent neuroimaging studies have shown that especially the rostral cingulate zone (RCZ) and the dorsolateral prefrontal cortex (DLPFC) become active during interference (Ridderinkhof et al., 2004; Carter and van Veen, 2007). The RCZ is thought to be involved in the detection of interference, whereas the DLPFC is thought to be involved in conflict resolution (Carter and van Veen, 2007). Following the logic of the standard Stroop task it is possible to create stimuli that evoke a synesthetic experience in synesthetes, which are congruent, neutral or incongruent with the primary task. Various studies (Dixon et al., 2004; Weiss et al., 2005; Berteletti et al., 2010) have shown that synesthetes show interference effects in such tasks comparable to those seen in the standard Stroop task, which can be seen as evidence for the automatic and involuntary nature of the synesthetic experience. Interestingly, the brain areas involved in this synesthetic interference effect partly overlaps with the network found in a standard Stroop task. In a first functional Magnetic Resonance Imaging (fMRI) study using a synesthetic Stroop task (Weiss et al., 2005) it has been shown that the left DLPFC was activated during interference trials as compared to neutral trials. Surprisingly, no interference related activation was found in the RCZ or related areas. This might have been caused by a number of drawbacks in this study. The synesthetically

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Abbreviations: CON, congruent; DLPFC, dorsolateral prefrontal cortex; EPI, echo-planar imaging; FFG, fusiform gyrus; fMRI, functional Magnetic Resonance Imaging; GLM, general linear model; IC, incongruent; NEU, neutral; RCZ, rostral cingulate zone; ROI, region of interest; RT, reaction time; TE, echo time; TOG, Test of Genuineness; TR, repetition time.

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caused interference effect was not directly compared to a more standard interference effect and only a small sample of synesthetes ($N = 9$) was studied without comparison with a non-synesthetic control group. The present study tried to solve these problems by including a control group, by adding a control condition and by using a larger sample. Furthermore, a block design optimized for fMRI studies based on recent findings (Mohanty et al., 2007) was used to prevent relatively weak activations often found in mixed, event-related designs (Evers et al., 2006). We hypothesized that only synesthetes would show a clear interference effect in a synesthetic Stroop task and that brain areas similar to areas involved in a standard Stroop task, including the DLPFC and the RCZ would be involved.

EXPERIMENTAL PROCEDURES

Participants

Participants were 13 women and two men with grapheme-color synesthesia (mean age 27.2, range 19–49), and 15 non-synesthetic controls matched for age, sex and level of education (mean age 27.4 years, range 18–46). Participants were recruited by contacting medical students and a call was posted on several websites and broadcast from the local radio station for synesthetes to participate in the research. Interested participants contacted us by email. Synesthetes were identified with an adapted Test of Genuineness (TOG) (Baron-Cohen et al., 1996). We asked all participants to complete this paper and pencil test, which consisted of 36 graphemes: all letters of the alphabet and all single digits 0–9. Participants were asked to describe in words what synesthetic color was experienced for each specific grapheme. Synesthetes were also asked to send us the exact colors experienced for four graphemes, which are experienced as most dominant. In order to get clearly distinguishable colors, we explicitly asked for letters associated with the colors red, yellow, blue and green. If these colors were not available, distinguishable alternatives were chosen. Moreover, we asked the synesthetes for symbols not eliciting synesthetic experiences. Both the four graphemes and the four symbols the synesthetes reported to us were used in the synesthetic Stroop task. A retest was done at our facility, for synesthetes this was done somewhat later (mean = 48.5 days, SD = 13.9) than for healthy controls (mean = 16.6 days, SD = 11.5). A jury of four independent persons judged the consistency of all participants, 1 point was given if the description of the grapheme in the first test exactly matched the description in the retest (e.g. in both tests a grapheme is described as light green), 0.5 points were given if the juror thought that the description in the first test partly matched the description in the second test (e.g. in the first test a grapheme is described as light blue, in the second test as blue). No points were given if the descriptions did not match. An average score was computed by averaging the scores of the four jurors and all items and converting this score to percentages (100% = 100% consistent). Synesthetes were very consistent over time (after exclusion of one synesthete) mean = 87.8%; range = 71.9–97.6%), while non-synesthetic controls were not at all consistent (after exclusion of one non-synesthete mean = 33.0%; range = 5.6–48.3%). Two participants were excluded, one synesthete and one control, because of scoring too low on the TOG (for synesthetes: < 70%), or for scoring too high on this test (for controls: > 50%). Other exclusion criteria were a history of neurological or psychiatric disorders, other important health problems, use of prescription medication other than oral contraception, excessive alcohol or drug use, metal implants or other contra-indications for fMRI. The study design was approved by the committee of Medical Ethics of Erasmus MC. All participants gave written informed consent and after completing the experiment, participants were paid 25 euro.

Stimuli

Stimulus presentation in both the normal and the synesthetic version of the Stroop task was based on Mohanty et al. (2007) who developed a version of the Stroop task that is optimized for fMRI experiments. In both the synesthetic and standard Stroop task participants were instructed to indicate the real color of the stimulus by pressing the corresponding button on a response device. In both tasks, three different types of blocks of stimuli were presented, i.e., neutral, congruent and incongruent blocks. A total of four congruent, four incongruent and eight neutral blocks were presented in both conditions. Each block consisted of 16 stimuli which were presented for 2 s each, resulting in a block length of 32 s per block. In the neutral blocks only neutral stimuli were presented. Both congruent and incongruent blocks were mixed blocks, consisting of both neutral and incongruent or congruent stimuli. In all congruent blocks eight congruent and eight neutral stimuli were presented. In all incongruent blocks eight incongruent and eight neutral stimuli were presented. This resulted in a total of 32 incongruent stimuli, 32 congruent stimuli, 32 neutral stimuli presented in incongruent blocks, 32 neutral stimuli presented in congruent blocks and 128 neutral stimuli presented in neutral blocks for both conditions. Between blocks we presented the Dutch word for rest ('RUST') for 8 s. In the standard Stroop task we used neutral words presented in four different colors as neutral stimuli, four different color words presented in the same color as congruent stimuli and four different color words presented in a different color as incongruent stimuli. As neutral words we used neutral (no color/no emotion) mono-syllabic or bi-syllabic Dutch words, varying in length between 5 and 7 letters. In the synesthetic Stroop task we used four individually chosen symbols that did not elicit a synesthetic experience as neutral stimuli, four individually chosen symbols that elicited a synesthetic experience presented in the color that the individual participant experienced as congruent stimuli and the same symbols that elicited a synesthetic experience presented in a different color as incongruent