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THE TASTE-VISUAL CROSS-MODAL STROOP EFFECT: AN EVENT-RELATED BRAIN POTENTIAL STUDY

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Abstract—Event-related potentials (ERPs) were recorded to explore, for the first time, the electrophysiological correlates of the taste-visual cross-modal Stroop effect. Eighteen healthy participants were presented with a taste stimulus and a food image, and asked to categorize the image as "sweet" or "sour" by pressing the relevant button as quickly as possible. Accurate categorization of the image was faster when it was presented with a congruent taste stimulus (e.g., sour taste/image of lemon) than with an incongruent one (e.g., sour taste/image of ice cream). ERP analyses revealed a negative difference component (ND430-620) between 430 and 620 ms in the taste-visual cross-modal Stroop interference. Dipole source analysis of the difference wave (incongruent minus congruent) indicated that two generators localized in the prefrontal cortex and the parahippocampal gyrus contributed to this taste-visual cross-modal Stroop effect. This result suggests that the prefrontal cortex is associated with the process of conflict control in the taste-visual cross-modal Stroop effect. Also, we speculate that the parahippocampal gyrus is associated with the process of discordant information in the taste-visual cross-modal Stroop effect.

Key words: Stroop effect, conflict control, cross modality, event-related brain potentials.

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Abbreviations: ACC, anterior cingulate cortex; ANOVA, analysis of variance; EEG, electroencephalography; EOG, electrooculogram; ERPs, event-related potentials; fMRI, functional magnetic resonance imaging; HEOG, horizontal electrooculogram; M, mean; ND, negative difference; PCA, principal component analysis; PFC, prefrontal cortex; SD, standard deviation; VEOG, vertical electrooculogram.

INTRODUCTION

Selecting appropriate foods for ingestion is critical for the survival of an organism. The decision to ingest or reject a selected food mostly relies on the evaluation of its multisensory properties such as its taste, its odor, its somatosensorial qualities and its visual appearance (de Araujo and Simon, 2009). For instance, an organism might first form expectations based on the visual appearance of the food, and then react to coherent or incoherent gustatory, olfactory and somatosensorial inputs. This example shows that studying how the brain integrates inputs coming from multiple senses, and how it monitors the conflict occurring between them is important for the understanding of fundamental decision processes. In the current study, we used event-related potentials (ERPs) in combination with a novel cross-modal taste-visual Stroop task to examine how the brain monitors the conflict that occurs when gustatory and visual information are discordant.

Conflict control is a commonly investigated form of cognitive control that refers to the ability to focus limited attention on relevant information and avoid the interference of irrelevant information (Heinemann et al., 2009). Conflict control is often studied in interference tasks, such as the Stroop task. In a classic Stroop task, the participant has to name, as quickly as possible, the hue of the color word displayed on a screen. This color word is either written in a congruent ink color (e.g., the word 'red' in red ink) or in an incongruent ink color (e.g., the word 'red' in green ink). The Stroop effect refers to the shorter reaction time in congruent than in incongruent trials (Stroop, 1935).

Previous the functional magnetic resonance imaging (fMRI) studies on the color-naming Stroop task evidenced a robust activation in the anterior cingulate cortex (ACC) related to the Stroop effect. An additional brain area that exhibited an increased activation was the prefrontal cortex (PFC) (Carter et al., 1995; Roelofs and Hagoort, 2002; Kerns et al., 2004; van Veen and Carter, 2005). Measurement of fMRI provides better spatial resolution of neural activity, thereby making fMRI a favorable measure for recording precisely the brain activation associated with the Stroop effect. However, its ability to inform us about the timing of activations is weaker. Electroencephalography (EEG), on the other hand, is better suited for these kinds of investigation. The ERP technique, which is better suited to explore the time course of cognitive

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processes, has also been used to investigate the Stroop effect. ERP studies on the classic Stroop task reported a significant negative incongruent vs. congruent difference wave occurring between 350- and 550-ms post-stimulus (Liotti et al., 2000; Markela-Lerenc et al., 2004; Qiu et al., 2006). Such negative deflection is believed to reflect the monitoring of the conflict between the incongruent information. In agreement with fMRI results, dipole source analyses also revealed independent generators in the ACC and the PFC regions (Liotti et al., 2000; Markela-Lerenc et al., 2004; Qiu et al., 2006).

Evidence suggests that Stroop-like effects can also take place between sensory modalities. For instance, Pauli et al. (1999) showed that odors acting as primes for smell-related words can modulate the naming speed of the ink color of these words (e.g., "fragrant" in red or "foul" in red). Relatedly, White and Prescott (2007) observed that the participants identified a taste more quickly when it was presented with a congruent odor (e.g., sweet taste with strawberry odor) than with an incongruent one (e.g., sour taste with strawberry odor). Such cross-modal Stroop-like effects suggest that conflicting information, which originates from different sensory systems, can compete for cognitive resources. So far, no study has ever investigated the taste-visual cross-modal Stroop effect. The aim of the present study was (1) to check for a possible Stroop-like effect in a taste-visual cross-modal Stroop task, and (2) to investigate the electrophysiological correlates of conflict control in this task, using high-density ERP recording and dipole source analysis.

Past studies showed that the control of the response conflict is an important component of cross-modal information integration (Alais and Burr, 2004; Körding and Wolpert, 2006). Therefore, one goal of the present study was to uncover which modulation of the ERPs is related to the conflict control process during the taste-visual cross-modal Stroop task. As mentioned above, many ERP studies on the Stroop effect found a negative difference (ND) wave (incongruent minus congruent) between 350- and 550-ms post-stimulus, and argued that this finding might be related to the monitoring of the conflict between information (Rebai et al., 1997; Liotti et al., 2000; Markela-Lerenc et al., 2004; Qiu et al., 2006). Since a similar conflict was expected to occur between the visual and the gustatory stimulus, a ND wave (incongruent minus congruent) was also anticipated in this study. In addition, we expected the brain areas involved in the taste-visual cross-modal Stroop task to be different from those reported in the classic Stroop task because the neural mechanism for multisensory information processing has already shown to be different from the neural mechanism elicited by inputs from a single sensory modality (Thesen et al., 2004; Macaluso and Driver, 2005; Macaluso, 2006). To this regard, we expected the dipole source analysis to reveal a generator in the PFC since this area is believed to be involved in the processing of multisensory interference (see Fuster et al., 2000; Xiao et al., 2011).

EXPERIMENTAL PROCEDURES

Participants

One hundred and sixteen volunteers were recruited from the network (university students from Chongqing of China). All of them had to first indicate, on a scale going from -2 (strong disgust) to 2 (strong delight), how they felt about the flavor of a crystal sugar and a Vitamin C tablet. Eighteen of them rated these stimuli as "neutral" (corresponding to 0 on the scale). Only these 18 participants, that is 10 men and eight women, were kept for the rest of the study.

The selected volunteers were aged between 20 and 25 years (mean (M) = 23.1, standard deviation (SD) = 1.3 years). All of them were healthy and right-handed, and all had normal or corrected to normal vision. None of them reported any allergy to sour or sweet food. The experiment was approved by the Academic Committee. A written informed consent was obtained from all participants prior to the experiment, and a monetary compensation was given to them after its completion.

Stimuli

The visual stimuli included 10 digital images of ordinary food items. Five of these images depicted typical sour foods: green plum, lemon, lime, vinegar, and vitamin C. The remainder represented typical sweet foods: ice cream, chocolate, butter cake, sweet dumplings and crystal sugar. Note that the category to which these images belonged was not ambiguous. In fact, none of the extra 70 students (36 males and 34 females) made a mistake when asked to categorize the images as sour or sweet food item. Before the beginning of the experiment, the selected group of 18 participants underwent a 2-min familiarization session with the images, then an identification task, and finally a sweet/sour categorization task. No error was made. The sour or sweet taste sensations were evoked by putting a 500-mg vitamin C tablet or a 2000-mg crystal sugar cube on the tongue of the participant.

Procedure

Participants were seated in a quiet room facing a computer monitor (the eye to screen distance was 60 cm), and were instructed to judge, as rapidly as possible, the flavor of the food depicted in the image by pressing the appropriate response key. Participants had to complete four blocks of 30 trials each, for a total of 120 trials. Just before the beginning of a block, the experimenter put either a cube of sugar or a vitamin C tablet on the participant's tongue, and instructed him/her to keep it in his/her mouth for the whole duration of the block. To avoid gustatory desensitization, successive blocks did not have the same gustatory stimulus. Between each block, participants also had to take a 150-s rest during which they had to gargle with purified water–this helped fade the flavor away in the oral cavity. It took about 40 s to complete a single block. Half the