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Short communication

Emotional content of stimuli improves visuospatial working memory

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HIGHLIGHTS

- Visuospatial working memory processing showed a facial emotion-related effect.
- Spatial working memory maintenance is affected by visual processing of happy faces.
- N170 is sensitive to happy faces while performing a VSWM task.
- P2 and LPP components showed happy face-triggered effects in a VSWM task.

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ABSTRACT

Processing and storage in visuospatial working memory (VSWM) seem to depend on attention-based mechanisms. In order to explore the effect of attention-attractive stimuli, such as emotional faces on VSWM performance, ERPs were obtained from 20 young adults while reproducing spatial sequences of six facial (happy and neutral) and non-facial control stimuli in inverse order. Behavioral performances revealed that trials with happy facial expressions resulted in a significantly higher amount of correct responses. For positive emotional facial stimuli, N170 amplitude was higher over right temporo–parietal regions, while P2 amplitude was higher over frontal and lower over parietal regions. In addition, LPP amplitude was also significantly higher for this type of stimuli. Both behavioral and electrophysiological results support the notion of the domain-general attention-based mechanism of VSWM maintenance, in which spatial to-be-remembered locations might be influenced by the emotional content of the stimuli.

1. Introduction

The on-line manipulation of different environmental visual stimuli involves working memory. Working memory (WM) is a theoretical construct used to refer to a limited capacity system or mechanism underlying the maintenance of task-relevant information during the performance of a cognitive task [1,2]. In brief, WM allows us to use information that is not currently available in the immediate environment.

The WM visuospatial sketchpad, a so-called slave system postulated by Baddeley and Hitch [1], was originally conceived as a spatial storage. However, opposing perspectives have been assumed by Logie [3] and several other authors who have hypothesized that visuospatial WM includes both object-based and spatial types of information, but that they are processed by different visual and spatial components [4].

Alternatively, Barrouillet et al. [5] postulated the time-based resource-sharing (TBRS) model of WM, which states that a general attention resource has to be shared between processing and storage activities. According to this model, forgetting could be explained as an effect of central interference caused by processing activities that divert attention from refreshing decaying memory traces. In fact, it has been found that spatial WM maintenance could be disrupted by visual processing, and that visual maintenance could be disrupted by spatial processing [6], which contradicts the notion of the domain-based fractionation of the visuospatial system into a visual component and a spatial component.

Since attention seems to be crucial for maintenance and load-related visuospatial working memory processes, the present study focuses on the effects that the attention-attractiveness

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of the content of the stimuli has on their spatial manipulation in WM. Specifically, we aimed to evaluate whether strong attention-attractive stimuli, such as emotional faces, could influence visuospatial WM maintenance, and operation. Emotional facial expressions are particularly salient stimuli for conveying other people's affective dispositions. Due to their social importance, emotional faces are identified accurately and faster than other changing objects [7].

Evidence suggests that affective information contained in facial expression is perceived involuntarily [8] and is capable of modifying the focus of attention [9]. In addition, several findings put forward that responses to facial emotional stimuli, especially fear and happiness, are modulated by attentional processes [10–12]. Furthermore, happy faces have been found to significantly affect the allocation of spatial attentional resources [13].

In this context, an experimental paradigm was designed, in which stimuli were presented at different locations on a touch screen video monitor and the participants had to remember the sequential order and location of each stimulus. Then, after a delay period, subjects had to reproduce the spatial location of each stimulus in the opposite order of the original presentation. Trials consisted of 6 happy faces, 6 neutral faces, or 6 neutral squares with simultaneous EEG recording. In order to better evaluate the temporal order of the cognitive-related events, event-related potentials (ERP) were obtained for the appearance of the last stimulus in each sequence category.

Event-related potentials have been successfully used to evaluate working memory and face processing, where several components have been associated with different stages of face evaluation, encoding, and retrieval. In the present study, due to their relation with facial emotions and attentional processing, the analyses will focus on early and late ERP components: N170, P2, and the late positive potential (LPP).

N170, a negative component that is thought to originate from posterior-lateral occipito-temporal cortex [14], is considered to reflect structural facial encoding. Even though face-specificity of N170 seems undeniable, the emotional modulation of this component appears to depend on specifications of the experimental setup.

P2 is an attention-related positivity peaking at approximately 200 ms; it might be sensitive to facial emotion and has been documented as reflecting learning and a deeper processing of stimuli [15].

LPP, which has been shown to be prominent over midline centro-parietal regions during the attentive processing of positive emotional facial expressions, is thought to index sustained processing and encoding of emotional stimuli in fronto–parietal brain networks, as a probable expression of a continued and deeper evaluation of emotional stimuli [16].

Following the TBRS model, we hypothesized that attention-attractive stimuli as emotional faces might unsettle the attentional processing required to maintain spatial information in WM, thus leading to poorer behavioral performances. Specifically, we predicted that when performing a visuospatial WM task, trials including faces as stimuli would impoverish the execution by leading to a decrease in the number of correct responses and longer response times with respect to trials with non-facial stimuli. In addition, we expected this effect to be more pronounced when using emotional, easily recognizable facial stimuli, such as happy faces. With regard to the ERP components, higher voltage amplitude of N170 for emotional faces, as well as higher P2 and LPP were initially expected, due to the task-related need to encode and retain the stimuli locations then affecting N170 [17], along with the effect of the attentional attractiveness of the emotional facial content on P2 and LPP [15,16].

2. Methods

2.1. Subjects

A total of 20 healthy, university volunteers (13 males) participated in the experiment (mean age = 25.5, SD = 5.62 years). Inclusion criteria were right-handedness and normal or corrected-to-normal vision. Exclusion criteria were a personal or family history of drug abuse or psychopathology, epilepsy, head injury, and drug or alcohol use (within 24 h prior to testing), all of which were assessed through clinical interviews. All subjects gave their written consent to participate in the study after they were fully instructed of the experimental procedures. The study was previously approved by the ethics committee of the Neuroscience Institute.

2.2. Design and procedure

2.2.1. Behavioral data and experimental task

The task consisted of 90 trials corresponding to 3 experimental categories of visual stimuli: (1) neutral faces (30 trials); (2) happy faces (30 trials), and (3) squares (control condition, 30 trials). Facial categories consisted of 20 full-color, 16 × 13 cm photographs of Hispanic models (5 males, 5 females) with neutral and happy facial expressions. These facial expressions had been categorized correctly with a hit rate above 90% by a pool of 20 similar subjects in a previous pilot study, and subsequently used in other experiments [18]. Neutral squares (control; 10 images) were built by randomizing the pixels of all the facial image stimuli from neutral and happy faces.

Each image was presented 18 times to allow a pseudo-random assembly of 30 trials per condition. Each trial comprised 6 images from the same category (e.g., 6 neutral faces). The presentation order of the 90 trials was randomized and divided into 2 blocks of 45 trials each. After each block, subjects were allowed a brief resting period. The presentation order of the blocks was counterbalanced.

A spatial WM experimental design was used, consisting in the sequential presentation of a series of 6 stimuli, all shown in different areas of a 21" touch-screen monitor with a central white dot as the fixation point. Viewing distance was 60 cm. Each stimulus within a trial belonged to the same category (happy, neutral, or control). Unbeknownst to the participants, the screen area was divided by the software into 2 rows and 3 columns to define 6 identical regions where the stimuli could appear at random. Subjects were previously instructed and trained to inversely reproduce the sequence presented by pressing – as quickly as possible via the touch-screen device – the corresponding screen locations with their right index finger, as soon as the cue "RESPOND" appeared in the center of the screen.

Participants were seated comfortably in a quiet, dimly-lit room. Visual stimuli were presented on an SVGA monitor (refresh rate: 100 Hz). Each stimulus was presented during 2000 ms with an inter-stimulus interval of 1500 ms. The command "RESPOND" lasted 1500 ms and was followed by a screen-in-black period with maximum duration of 5000 ms while responses were submitted. If the response was completed before this time period, then the next trial was triggered automatically. Fig. 1 illustrates the experimental flow chart.

2.2.2. ERP acquisition

EEGs were recorded and ERPs obtained in all the experimental design categories from 100 ms before the onset of the stimuli until 1000 ms after it. Stimulus-locked ERPs were recorded, only for the last stimulus in each sequence, from the Fp1, Fp2, F7, F8, F3, F4, C3, C4, P3, P4, O1, O2, T3, T4, T5, T6, Fz, Cz, and Pz scalp electrode sites, according to the 10–20 system. Electrooculograms (EOGs)