Biological Psychology 119 (2016) 190–199

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Working memory of emotional stimuli: Electrophysiological characterization

Dominique Kessel[a,*], María J. García-Rubio[a], E. Kirstin González[b], Manuel Tapia[a], Sara López-Martín[a], Francisco J. Román[a], Almudena Capilla[a], Kenia Martínez[a,c], Roberto Colom[a], Luis Carretié[a]

[a] Facultad de Psicología, Universidad Autónoma de Madrid, Madrid, Spain
[b] Fachbereich Psychologie, Universität Koblenz-Landau, Landau, Germany
[c] Instituto de Investigación Sanitaria, Hospital General Universitario Gregorio Marañón, Madrid, Spain

ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 30 June 2016
Accepted 7 July 2016
Available online 9 July 2016

Keywords:
Working memory
N-back
Emotion
Faces
ERP
P3

ABSTRACT

Memorizing emotional stimuli in a preferential way seems to be one of the adaptive strategies brought on by evolution for supporting survival. However, there is a lack of electrophysiological evidence on this bias in working memory. The present study analyzed the influence of emotion on the updating component of working memory. Behavioral and electrophysiological indices were measured from a 3-back task using negative, neutral, and positive faces. Electrophysiological data evidenced an emotional influence on the working memory sensitive P3 component, which presented larger amplitudes for negative matching faces compared to neutral ones. This effect originated in the superior parietal cortex, previously reported to be involved in N-back tasks. Additionally, P3 results showed a correlation with reaction times, where higher amplitudes were associated with faster responses for negative matching faces. These findings indicate that electrophysiological measures seem to be very suitable indices of the emotional influence on working memory.

1. Introduction

Memorizing events associated with biologically relevant consequences (both positive and negative) is an efficient strategy favored by evolution. Indeed, studies on long term memory have shown that emotional information is preferentially encoded, consolidated, and retrieved, compared to non-emotional information (e.g., Hamann, 2001; Kensinger, 2004, 2007). However, the effect of emotion on working memory, a complex mnemonic system devoted to the temporary maintenance of relevant information (e.g., Baddeley, 2003; D'Esposito, 2007), is less well established. Within the working memory system, the *executive component* (e.g., Baddeley, 1996, 2003) may be of special interest when dealing with biologically relevant events (which are, by definition, emotional), because it has the function of regulating which part of the incoming information will be actively maintained in short-term memory (Miyake et al., 2000). Here, *updating* processes play a crucial role, since they are necessary for keeping track of the information managed by the working memory system (e.g., Miyake et al., 2000; Morris & Jones, 1990). Accordingly, a task tapping into these updating processes might be especially suitable for studying the emotional influence on working memory.

Updating tasks typically involve the online addition and subtraction of information in working memory. The present study will focus on the N-back task, a widely used measure for evaluating updating processes (e.g., Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Hockey & Geffen, 2004; Martínez et al., 2011; see Redick & Lindsey, 2013 for a review). In the N-back task, a sequence of stimuli is presented, and the participant is instructed to indicate whether or not the current stimulus matches the one that appeared N steps earlier in the sequence. Reaction times and error rates are the most employed behavioral indices for measuring performance and for analyzing the underlying working memory processes. The load factor N can be adjusted to manipulate task difficulty. Controlling task difficulty across participants is an appropriate strategy in studies exploring cognitive processing of emotion, since cognitive load has been proposed to modulate the influence of emotional contents on cognitive processes (e.g., Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Van Dillen, Heslenfeld, & Koole, 2009). In dual

* Corresponding author at: Facultad de Psicología, Universidad Autónoma de Madrid, 28049 Madrid, Spain.
E-mail address: dkessel.research@gmail.com (D. Kessel).

http://dx.doi.org/10.1016/j.biopsycho.2016.07.009
0301-0511/

tasks, cognitive load affects behavioral performance and event-related potentials (ERPs) amplitude in the same way as emotion (e.g., MacNamara, Ferri, & Hajcak, 2011; Van Dillen & Derks, 2012). Thus, in the present study (which employs a single task where emotion is the target), it seems advisable to control for difficulty, in order to ensure that differences between experimental conditions will be only due to the modulatory effect of emotion. One strategy to accomplish this purpose in N-back tasks, and which is adopted here, involves selecting participants who show their best performance in a particular N-back level (e.g., 3-back), while discarding those participants reaching levels above or below this threshold during a time limited training session (see Methods' section for further details). To the best of our knowledge, this is the first study considering the effect of emotion on working memory in which cognitive load has been equalized for all participants.

Regarding the updating process, behavioral studies employing emotional N-back tasks are not very numerous and results are not consistent. Thus, there is some evidence for an effect of valence. Specifically, happy faces have been found to be preferentially updated (Levens & Gotlib, 2010, 2012), and sad or fearful faces to produce higher interference in task performance (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012). Nevertheless, other data indicate a preference for fearful faces during updating (Luo et al., 2014). On the other hand, there is also evidence from a study employing sexual and crime scenes, indicating that stimulus arousal facilitates the updating process (Lindström & Bohlin, 2011).

Along with behavioral indices, ERPs have also been employed as indices of working memory, since they are especially suitable for studying rapid cognitive processes due to their millisecond resolution. Working memory neural mechanisms are mostly reflected in late positivities, concretely, in the P3 component. In this context, P3 amplitude reflects resource allocation, with larger amplitudes associated with higher cognitive involvement; latency indexes classification speed, which is proportional to the time required to detect and evaluate a target stimulus (e.g., Kok, 2001; Polich, 2007). Previous electrophysiological data indicate that experiencing an induced negative emotional state when performing a spatial letter updating task may decrease posterior P3 amplitude (Li, Li, & Luo, 2006), which points to a modulating effect of emotion on this component. However, to the best of our knowledge, up to now there are no ERP studies on the emotional influence on working memory employing emotion as the target stimulus to be updated, and directly addressing the following key points: First, the most sensitive ERP component for measuring the influence of emotion on working memory, as well as its topography, has not yet been determined; neither has the effect of emotion on amplitude and latency been analyzed. Second, it has not been clarified whether the modulating effect of emotion on working memory performance is preferentially driven by valence (negative *or* positive), or by arousal (both negative *and* positive).

Accordingly, the present study explored these issues, administering an emotional single 3-back task using negative, neutral and positive faces as stimuli, and measuring behavioral and electrophysiological indices. Participants were selected according to their previous best performance during an N-back training session, discarding those reaching levels lower or higher than the 3-back level. This strategy ensures that the level of cognitive load – a crucial factor modulating working memory, as explained above – is homogenized across participants. Based on previous results mentioned earlier, an advantage of emotional faces (negative, or both negative and positive, compared to neutral ones) during the updating process was expected, as evidenced by lower reaction times, smaller error rates, and enhanced ERP amplitudes in the memory-sensitive P3 component.

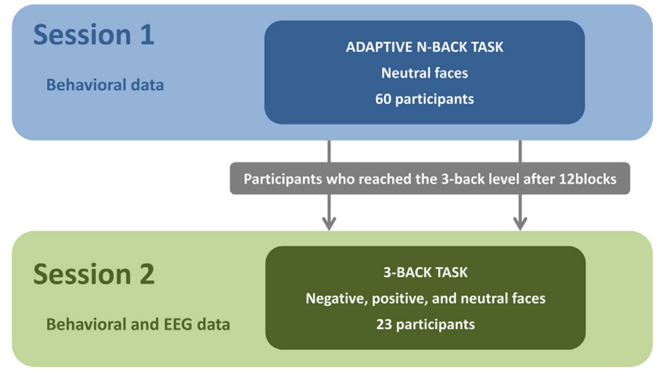

Fig. 1. Schematic illustration of participant selection.

2. Methods

2.1. Participants

Sixty students from the Universidad Autónoma de Madrid participated in the first session of this study (during which only behavioral data were measured). From this initial sample of 60 only those 23 who performed at the level of difficulty required for the experimental task (3-back) were selected for the second and main study (which also included electrophysiological measures). These remaining 23 participants (14 women) performed a 3-back task with emotional face stimuli (see Fig. 1, as well as the Procedure section, for details on participant selection). Ages ranged from 18 to 32 (mean = 22.4, SD = 3.6). All students participated voluntarily, after providing their informed consent according to the Declaration of Helsinki. They received course credit or a monetary compensation for their participation (€5 for the first session and €15 for the second session). They reported normal or corrected to normal visual acuity. The experiment was approved by the Research Ethics Committee of the Universidad Autónoma de Madrid.

2.2. Stimuli and procedure

As mentioned above, the study was composed of two sessions, held in sequence and separated by one week. Details are described in Fig. 1. During the first session, in order to classify their optimum N-back level, the initial 60 participants were exposed to an adaptive N-back task employing neutral faces. Thirty-two face stimuli[1] were taken from the FACES database (Ebner, Riediger, & Lindenberger, 2010). Participants were placed in front of a computer screen at a distance of 40 cm. Stimuli were presented using an application designed for the purpose of the study, based on Visual Basic. The task was presented in 12 blocks; each block was composed of 20 + N images (being N = 1,2, 3, etc., depending on the participant's current level of difficulty in the N-back task) of which six were matches. Matches were those stimuli that matched the one appearing N steps earlier in the sequence, and non-matches were those that did not. In order to control for confounding variables not related to the task, the same pictures were presented as matches and non-matches. Visual angle of all stimuli was 38° (width) × 29° (height),

[1] FACES database codes of the faces employed during session 1: Neutrality_011_45, Neutrality_013_22, Neutrality_021_80, Neutrality_026_54, Neutrality_029_48, Neutrality_038_46, Neutrality_040_24, Neutrality_043_54, Neutrality_057_22, Neutrality_063_27, Neutrality_070_45, Neutrality_073_55, Neutrality_087_39, Neutrality_093_47, Neutrality_097_54, Neutrality_098_20, Neutrality_105_21, Neutrality_117_45, Neutrality_122_53, Neutrality_123_20, Neutrality_125_21, Neutrality_127_28, Neutrality_132_20, Neutrality_139_45, Neutrality_142_55, Neutrality_147_22, Neutrality_149_51, Neutrality_150_20, Neutrality_155_45, Neutrality_159_54, Neutrality_160_28, Neutrality_170_31.