Biological Psychology 113 (2016) 75–82

Contents lists available at ScienceDirect

Biological Psychology

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

Novelty and emotion: Pupillary and cortical responses during viewing of natural scenes

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ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form
16 November 2015
Accepted 16 November 2015
Available online 26 November 2015

Keywords:
Emotion
Repetition
Pupil response
Late positive potential

ABSTRACT

Given the remarkable similarities in the antecedent conditions—stimulus motivational relevance and novelty (i.e., probability of occurrence)—that elicit amplitude modulation of the late positive potential (LPP) and the pupillary dilation response, the present study examines whether these two indexes of orienting response reflect common processes that are responsible for modulatory patterns in motivationally relevant contexts. In the present study, the LPP and the pupillary dilation response were co-registered in a free-picture viewing context in which stimulus novelty was manipulated through repeated presentation of the same picture exemplar. More specifically, pictures depicting both emotional and neutral contents could be novel, that is never seen before in the course of the study, or repeated 4–8 times in a row (i.e., massed repetition).

Results showed that, despite massed repetitions, the late positive potential amplitude continued to be highly modulated by picture content, whereas affective modulation of pupil dilation decreased with picture repetition.

These findings indicate that, although the LPP and pupil dilation are similarly affected by motivational relevance during the viewing of novel pictures, they differ when pictures are highly familiar, possibly reflecting different functional meanings in the context of the orienting response.

1. Introduction

The processing of novel and significant stimuli is crucial to protect and sustain the life of the individual. On one hand, new stimuli pose novel opportunities that may result in beneficial outcomes; on the other, new stimuli may pose a threat. Novel or emotional events induce a variety of physiological changes, which Sokolov (1963) collectively called the orienting response (OR). A defining feature of the orienting response was that these physiological changes were elicited in the context of stimulus change, and that orienting habituated with stimulus repetition.

Motivationally relevant stimuli, such as emotional scenes, can elicit an orienting response, which is observable as a modulation of a broad range of physiological reactions (Bradley, 2000; Lang, Greenwald, Bradley, & Hamm, 1993). Some of these reactions, especially those involving autonomic activation, have been shown to habituate rapidly with stimulus repetition (i.e., heart rate, skin conductance, Bradley, Lang, & Cuthbert, 1993; Codispoti, Ferrari, & Bradley, 2006), indicating that some processes engaged in the initial orienting response to motivationally relevant stimuli are no longer necessary when stimuli are repeated or expected.

At the cortical level, the centro-parietal late positive potential (LPP) is reliably modulated by motivational relevance (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Codispoti et al., 2009; Johnston, Miller, & Burleson, 1986; Radilova, 1982; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). This affective modulation begins approximately 200–400 ms following picture onset and develops into a sustained positive slow wave throughout the picture presentation period (1–6 s; Cuthbert et al., 2000; Gable, Adams, & Proudfit, 2015). The largest positive amplitudes have been observed for highly arousing picture contents, either pleasant or unpleasant, suggesting that the late positive potential is more clearly a brain response to stimulus motivational relevance, rather than to its valence (De Cesarei & Codispoti, 2011; Weinberg & Hajcak, 2010; Schupp, Cuthbert et al., 2004; Schupp et al., 2006). More-

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http://dx.doi.org/10.1016/j.biopsycho.2015.11.008
0301-0511/

over, unlike autonomic orienting responses, this cortical index of emotional processing has been found to be only slightly affected by picture repetition (Codispoti, Ferrari, De Cesarei, & Cardinale, 2006; Codispoti, Ferrari, & Bradley, 2007; Ferrari, Bradley, Codispoti, & Lang, 2011), consistent with the idea that the orienting response cannot be considered a unitary process (Barry & O'Gorman, 1987; Bradley, 2009; Codispoti, Ferrari, & Bradley, 2006).

One index of the orienting response that has been only recently investigated in the context of emotional picture viewing is the pupil dilation response (Bradley, Miccoli, Escrig, & Lang, 2008). Like the late positive potential amplitude, pupil diameter is larger during viewing of emotionally arousing pictures, pleasant or unpleasant, compared to neutral scenes, and this modulatory effect begins with the initial light reflex and persists throughout the picture viewing interval (Bradley et al., 2008; Henderson, Bradley & Lang, 2014). Moreover, recent animal studies suggest that pupillometry may be used as a useful index to study cortical arousal, as higher cortex desynchronization and stronger responsiveness to external stimuli have been observed during pupil dilation, as opposed to constriction (Reimer et al., 2014; Vinck, Batista-Brito, Knoblich, & Cardin, 2015).

Given the remarkable similarities in the antecedent conditions (i.e., stimulus relevance) that elicit the amplitude modulation of the LPP and the pupil dilation, the current study examines whether these two indexes of orienting response reflect common neural mechanisms that are responsible for modulatory patterns in motivationally relevant contexts. In human research, only a few studies have co-registered cortical activity (i.e., P3 component of event-related potentials) and pupil diameter within the same experiment, and found that they were highly sensitive to stimulus novelty, with both measures increasing in amplitude as the probability of occurrence of the eliciting stimulus decreased (Friedman, Hakerem, Sutton, & Fleiss, 1973; Murphy, Robertson, Balsters, & O'Connell, 2011; Verbaten, Roelofs, Sjouw, Slangen, 1986).

In the present study, the LPP and the pupillary dilation response were co-registered in a free-viewing context in which participants viewed blocks of novel pictures, emotional and neutral, alternated with blocks of massed repetitions, wherein the same picture exemplar was consecutively presented 4–8 times in a row.

The specific comparison between the affective modulation of the LPP and the pupillary dilation response as a function of repetition would be informative regarding the nature of the processes underlying their affective modulation: If modulatory differences in the LPP and in the pupil diameter as a function of affective picture content index the same processes, we expected similar effects of picture repetition. Therefore, based on previous findings (Bradley & Lang, 2015; Codispoti, Ferrari, De Cesarei et al., 2006; Codispoti et al., 2007; Ferrari et al., 2011), we expected that the viewing of repeated emotional pictures would prompt enhanced LPP and pupil diameter, compared to the viewing of repeated neutral pictures.

On the other hand, the affective modulation of the pupillary dilation response has been shown to covary with skin conductance changes (Bradley et al., 2008). Considering that skin conductance reactivity is clearly affected by picture repetition, showing a rapid habituation of the affective modulation following a few picture repetitions (Bradley et al., 1993), we might expect an enhanced sensitivity to picture repetition of the pupillary response modulation compared to the late positive potential.

2. Method

2.1. Participants

A total of 27 participants (14 females) took part in the study for course credits. Age ranged from 18 to 32 (M = 23.11, SD = 3.72). All participants had normal or corrected to normal vision, and none of them reported current or past neurological or psychopathological problems. The participants had no previous experience with the materials used in this experiment. The experimental protocol conforms to the declaration of Helsinki, and was approved by the Ethical Committee of the University of Bologna. Because of failure of the eye tracker, we could not collect pupil data from 5 participants. For pupil analyses, final Ns are 22 participants, females = 12.

2.2. Materials and design

The stimuli were 176 pictures selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and other sources, representing an equal number of emotionally arousing (pleasant and unpleasant) and neutral pictures. Pleasant categories included erotic couples, romance, families/babies, puppies and sports; unpleasant categories included mutilations, human threat, animal threat, disgust and accident, and neutral categories included faces and people in urban or domestic contexts.[1] Each picture was adjusted to an average luminance and contrast value and resized to 160 × 120 pixels. Of these, 32 (half emotional, half neutral) pictures were repeated across trials whereas the remaining pictures were presented only once (i.e., novel). Repetitions were consecutive (massed), and the number of repetitions was variable across trials (from four to eight times in a row). Novel pictures were presented in series from three to six pictures. Throughout the study, there were 32 series of repeated pictures and 32 series of novel pictures, for a total of 320 trials; novel and repeated series alternated regularly. Using the same 176 pictures, six pseudorandomized presentation orders were constructed that varied the specific pictures presented in the repeated and novel sets across participants.

To find the appropriate luminance and timing, which allow the pupil to recover from the light reflex (Ellis, 1981), we collected pilot data from 8 participants who did not take part in the final experiment. In this pilot group, we varied the inter-trial interval (ITI) and the luminance of the stimuli and background. Room illumination, picture as well as background luminance were measured using a diode-type digital luxmeter. The mean room illumination was 11 lux. The background color that surrounded the picture, also used as a background screen in the ITI, was black. The gray patch used to replace the picture during the ITI had a luminance of 10 lux. Pictures had an average luminance of 14.52 lux. Based on these pilot data and these luminance values, the average ITI was set to 5 s.

Each trial consisted of the presentation of a gray blank patch (sized 160 × 120 pixels) at the center of a black screen for 2 s. In place of the gray patch, a picture was displayed for 4 s, and was again followed by a gray patch lasting 3 s, plus or minus a random additional time between 0 and 250 ms (average ITI: 5 s ± 250 ms).

2.3. Apparatus

Participants were seated in front of a SMI RED 500 remote eye tracking system, positioned below a 22-in LCD monitor on which the pictures were presented and situated approximately 52 cm

[1] Picture set comprised both IAPS and non-IAPS pictures. More specifically, non-IAPS pictures were selected from public domain pictures available on the Internet, and from document scanning, with the purpose to reach a sufficient number of images in the neutral category (n = 88). Examples of some IAPS images used in the study that closely resemble the neutral non-IAPS pictures are: 2110, 2390, 2396, 2595, 2036, 2339, 2102, 2191, 2357, 2372, 2374, 2377, 2384, 2400, 2411, 2488, 2489, 2521, 2635, 2745, 7493, 7550. Pleasantness (p) and arousal (a) mean (standard deviation) ratings for IAPS neutral pictures: p = 5.4 (.5); a = 3.7 (.4); pleasant pictures: p = 7.2 (.6); a = 5.6 (1.1); unpleasant pictures: p = 2.3 (.7); a = 6.3 (.7).