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Motivational significance and cognitive effort elicit different late positive potentials

Izumi Matsuda [a,*], Hiroshi Nittono [b]

[a] National Research Institute of Police Science, Chiba, Japan
[b] Graduate School of Integrated Arts and Sciences, Hiroshima University, Higashi-Hiroshima, Japan

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HIGHLIGHTS

- The late positive potential (LPP) can be decomposed into two subcomponents.
- A central–parietal dominant LPP is elicited by motivationally significant stimuli.
- An occipital dominant LPP would be associated with effortful, controlled processing.

ABSTRACT

Objective: The interaction between affective and cognitive processes has been examined using the late positive potential (LPP) component of the event-related brain potential. The LPP is elicited not only by affective stimuli but also by nonaffective stimuli that require effortful cognitive processing. However, it is unclear whether these LPPs are equivalent. The present study decomposed the LPP into subcomponents that responded differently to affective content and cognitive demands.
Methods: The participants ($N = 21$) performed four types of revised oddball tasks, in which one affective and five nonaffective pictures were presented. For one of the nonaffective pictures, different cognitive demands were loaded: viewing the display, updating a count, updating two different items, or concealing knowledge of the picture.
Results: A temporal–spatial principal component analysis revealed two major subcomponents of the LPP. The central–parietal subcomponent was elicited by affective stimuli, whereas the occipital subcomponent was elicited by nonaffective stimuli with cognitive demands in the two-item updating and concealment conditions.
Conclusions: The results suggest that the central–parietal dominant LPP may reflect motivated attentional processing, whereas the occipital dominant LPP may reflect effortful controlled processing.
Significance: Dealing with these two LPP subcomponents separately may be useful for examining the interaction between affective and cognitive processing of stimuli.

1. Introduction

The interaction between affective and cognitive processes has attracted attention from researchers for decades. Recently, the late positive potential (LPP), a component of the event-related potential (ERP), has been measured to investigate this interaction (for a review, see Weinberg et al., 2013). The LPP is a midline ERP that becomes evident approximately 300 ms following stimulus onset. The increased positivity extends well beyond 1000 ms. The LPP is often overlapped by another component, P3, which is a parietal positivity that occurs 250–500 ms after stimulus onset and reflects phasic attentional resource allocation to the stimulus (Polich, 2007). However, the longer duration of the LPP suggests that it is at least somewhat distinct from the P3 (Hajcak et al., 2010).

Many studies have reported that the LPP is elicited by affective content. The LPP is larger following both pleasant and unpleasant stimuli than following neutral stimuli (Cuthbert et al., 2000; Schupp et al., 2000). The LPP is observed in passive viewing of affective stimuli. It does not appear to habituate over repeated

* Corresponding author. Address: National Research Institute of Police Science, 6-3-1 Kashiwanoha, Kashiwa, Chiba, Japan. Tel.: +81 471 35 8001; fax: +81 471 33 9153.
E-mail address: izumi@nrips.go.jp (I. Matsuda).

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presentations of stimuli (Codispoti et al., 2006; Olofsson and Polich, 2007). At the same time, the LPP is also affected by top-down cognitive processes. The LPP for task-irrelevant affective stimuli decreases as a function of increasing cognitive load, such as an increase in the number of letters that the participants are asked to memorize (MacNamara et al., 2011). The LPP also decreases when the participants are directed to attend to a nonarousing portion of aversive images (Dunning and Hajcak, 2009). These findings are in contrast with the characteristics of early ERP components (e.g., <300 ms) elicited by affective stimuli. The early components are less subject to cognitive demands of concurrent tasks (Foti and Hajcak, 2008; Schupp et al., 2008). Therefore, the LPP elicited by affective stimuli is thought to reflect more flexible and elaborated processing of affective stimuli, rather than obligatory attentional capture, as reflected by the early components (Weinberg et al., 2013). The topography of this type of LPP is usually parietal dominant, although some studies reported additional positivity at central and occipital sites (Foti et al., 2009).

On the other hand, some studies have shown that nonaffective stimuli that require effortful cognitive processing elicit the LPP, which has often been called a *positive slow wave*. For example, equivocal information increases the LPP because equivocation requires further cognitive processing after one has detected the information (Ruchkin et al., 1982). The task requirement of updating two or three memorized items after target detection induces a larger LPP than simple updating of a target count because the former requires greater cognitive effort (García-Larrea and Cézanne-Bert, 1998). In a related example, information that the participants were required to conceal elicited a larger LPP than information that they did not have to conceal, because the participants intentionally sought to control their responses (Matsuda et al., 2009; Matsuda et al., 2011, 2013). Comparing these results yields the conclusion that the LPPs in these studies appear to occur when the participants are engaging in effortful cognitive processing after identifying task-relevant stimuli. The LPP associated with cognitive effort has a parietal or occipital dominant distribution (Anurova et al., 2005; García-Larrea and Cézanne-Bert, 1998; Matsuda et al., 2013), sometimes with negative potentials in frontal regions (McCallum et al., 1983).

Although the LPP is elicited not only by affectively arousing stimuli but also by stimuli that require effortful cognitive processing, it is still unclear whether the LPP associated with affective arousal and that associated with cognitive effort are equivalent. There are two possible hypotheses. First, the same LPP is influenced by both affective content and cognitive demands. Second, there are several LPP subcomponents with different scalp topographies, each of which responds differently to affective content and cognitive demands.

In the present study, we attempted to decompose the LPP into subcomponents that responded differently to affective content and cognitive demands. The participants performed four types of revised oddball tasks, in which one affective and five nonaffective pictures were presented. For one of the nonaffective pictures, one of the four tasks was added to provide variation in cognitive demands. The four possible tasks were (a) simply to view the display, (b) to update the count of the nonaffective picture presented, (c) to update two different items (i.e., month and date), or (d) to conceal their knowledge of the nonaffective picture. The passive viewing task was introduced to examine the LPP elicited by affective content without cognitive demands. The counting and two-item updating tasks were introduced to replicate the previous finding that the increase in cognitive demands increased the LPP's amplitude (García-Larrea and Cézanne-Bert, 1998). The concealment task was introduced to examine whether a different manipulation of cognitive demands exerts a similar effect on the LPP. To dissociate the processing of affective content from the processing of cognitive demands, we made all the affective images irrelevant to the task. This manipulation allows a fair comparison of the ERPs elicited by affective images across conditions.

The LPPs for all pictures in all four tasks were gathered and decomposed into several spatial subcomponents according to differences in topographic characteristics by using principal component analysis (PCA). Then we investigated the responses of each LPP subcomponent to affective content and cognitive demands. Should we find LPP subcomponents that modulated differently for affective content and cognitive demands, we can then conclude that these subcomponents not only had different spatial characteristics but also reflected different types of processing.

For a manipulation check, we also examined ERP components other than the LPP, namely the P3 and early posterior negativity (EPN). The EPN peaks 150–300 ms after the presence of arousing stimuli, and presents as a negative deflection over temporal–occipital sites and as a positive deflection over frontal–central sites (Schupp et al., 2006). Based on the findings of previous studies, we expected that affective pictures would elicit larger EPN and P3 (for a review, see Olofsson et al., 2008). The P3 was also expected to increase for nonaffective, task-relevant stimuli in the counting; two-item updating; and concealment conditions (Polich, 2007; Rosenfeld, 2011).

2. Method

2.1. Participants

Twenty-six healthy volunteers (13 men and 13 women, 21–41 years old, $M = 32.4$, $SD = 5.6$) participated in the experiment. All participants had normal or corrected-to-normal vision and were right-handed according to the Edinburgh Inventory (Oldfield, 1971). All of them gave informed consent. The participants were paid 5000 yen (equivalent to approximately US $50) after taking part in the experiment. The research ethics committee of the National Research Institute of Police Science approved the study.

2.2. Stimuli

Four stimulus sets were prepared. Each stimulus set consisted of six pictures selected from the International Affective Picture System (IAPS; Lang et al., 2005).[1] One of the six pictures was an affective picture and the other five were nonaffective. Normative ratings indicated that the affective pictures were less pleasant ($M = 2.37–3.95$, $SD = 1.57–2.22$) and more arousing ($M = 6.03–7.35$, $SD = 1.68–2.38$) than the nonaffective pictures ($M = 4.43–5.55$, $SD = 0.60–1.46$ for pleasantness; $M = 1.72–3.84$, $SD = 1.26–2.09$ for arousal). Each picture was presented on a 17-in cathode ray tube display at a distance of 100 cm with a visual angle of $12.9° \times 9.68°$. Before the experiment, the participants evaluated subjective pleasantness and arousal for each of the 24 pictures (4 sets × 6 pictures) using a self-assessment manikin (SAM; Bradley and Lang, 1994).

2.3. Procedure

Each of the four stimulus sets was used for each of the following four conditions: passive viewing, counting, two-item updating, and concealment (Fig. 1). The combinations of stimulus set and condition were counterbalanced across the participants. In each condition, one affective and five nonaffective stimuli were randomly presented on the screen. In the counting, two-item

[1] The IAPS pictures used in the experiment are as follows: Stimulus Set 1: 6230 (unpleasant), 7004, 7006, 7010, 7031, 7175 (nonaffective); Stimulus Set 2: 1220 (unpleasant), 7000, 7009, 7060, 7100, 7190 (nonaffective); Stimulus Set 3: 1200 (unpleasant), 7002, 7030, 7038, 7080, 7233 (nonaffective); Stimulus Set 4: 1930 (unpleasant), 7020, 7034, 7040, 7050, 7090 (nonaffective).