

Directed and Motivated Attention during Processing of Natural Scenes

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Abstract

■ Visual attention can be voluntarily oriented to detect target stimuli in order to facilitate goal-directed behaviors. Other visual stimuli capture attention because of motivational significance. The aim of the present study was to investigate the relationship between directed and motivated attention using event-related potentials. Affectively engaging pictures were presented either as target stimuli or as nontargets in a categorization task. Results indicated that both task relevance and emotional significance modulated the late positive potential

(LPP) over centro-parietal sensors. Effects of directed and motivated attention on the LPP were additive, with the largest centro-parietal positivity found for emotional pictures that were targets of directed attention, and the least for neutral pictures that were nontargets. Taken together, the data provide new information regarding the relationship between motivated and directed attention, and suggest that the LPP reflects the operation of attentional neural circuits that are utilized by both top-down and bottom-up processes. ■

INTRODUCTION

Visual attention can be voluntarily directed to target stimuli in order to perform specific detection, categorization, or evaluation tasks. Alternatively, some stimuli seem to automatically capture attention because they are inherently significant. In general, these are two modes by which attention is implicated in stimulus processing: First, in a top-down or goal-directed fashion as a function of instructions or task, and second, in a bottom-up or stimulus-driven manner that occurs by virtue of intrinsic properties of a stimulus. Here, we explore how these two modes of attention interact during perception of natural scenes.

When individuals direct attention to target stimuli that have been defined according to specific stimulus features (e.g., size, color, or shape), a larger late positive potential (LPP) over centro-parietal sensors is observed for target, compared to nontarget, stimuli in a time window lasting from 350 to 700 msec (Azizian, Freitas, Parvaz, & Squires, 2006; Polich, 2003; Kok, 2001; Näätänen, 1992; Ritter & Ruchkin, 1992; Johnson, 1986; Hillyard & Münte, 1984; Hillyard & Kutas, 1983; Roth, 1983; Donchin, 1981; Hillyard, Picton, & Regan, 1978). This potential is often interpreted as reflecting the additional attentional capacity invested in categorization of task-relevant events (Kok, 2001; Luck & Hillyard, 2000).

Although much of the literature on event-related potential (ERP) changes associated with stimulus categori-

zation have used simple stimuli (geometric figures, tones, letters, etc.), similar findings have been obtained using complex visual stimuli such as natural scenes (Codispoti, Ferrari, Junghöfer, & Schupp, 2006; De Cesare, Codispoti, Schupp, & Stegagno, 2006; Goffaux et al., 2005; Batty & Taylor, 2002; Antal, Keri, Kovacs, Janka, & Benedek, 2000). For instance, Codispoti, Ferrari, Junghöfer, et al. (2006) used an ultra-rapid categorization task (Thorpe, Fize, & Marlot, 1996), in which participants were asked to decide whether briefly presented natural scenes contained an animal or not: Target stimuli prompted a larger positive wave than nontarget stimuli, beginning around 300 msec following stimulus onset that was maximal over centro-parietal sensors, suggesting increased attention specifically to targets during the categorization process.

Much evidence also indicates that emotional scenes naturally capture attention (Bradley, Codispoti, & Lang, 2006; Bradley, 2000). Consistent with this, a second line of research has shown that ERPs measured during passive picture viewing vary with emotional arousal, with affective (either pleasant or unpleasant) eliciting a larger LPP than neutral pictures from about 300–800 msec over the centro-parietal cortex (Codispoti, Ferrari, & Bradley, 2007; Schupp, Junghöfer, Weike, & Hamm, 2004; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Johnston, Miller, & Burleson, 1986; Radilova, 1982). This effect has been interpreted as reflecting motivated attention, in which motivationally significant stimuli reflexively engage attentional resources (Lang, Bradley, & Cuthbert, 1997).

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The aim of the present study was to investigate the relationship between directed and motivated attention, as indexed by late positive ERPs, by asking participants to direct attention (or not) to affectively engaging stimuli. Although modulation of earlier ERP components have sometimes been attributed to attention or emotion, a variety of additional factors (i.e., perceptual or sensory processes) have been invoked at early stages of picture processing (Bradley, Hamby, Low, & Lang, 2007; Codispoti et al., 2007; Rousselet, Macé, Thorpe, & Fabre-Thorpe, 2007; De Cesarei & Codispoti, 2006; Philiastides, Ratcliff, & Sajda, 2006; Doninger et al., 2000; Heslenfeld, Kenemans, Kok, & Molenaar, 1997), leading us to focus on the late centro-parietal LPP. We used a directed attention paradigm in which pictures of humans (pleasant, neutral, unpleasant), animals, and objects were briefly presented (30 msec) and participants were instructed to perform one of two visual categorization tasks: In one task, participants were asked to decide whether each picture contained an animal or not (directed attention to animals), whereas in the second task, participants decided whether each picture contained a human or not (directed attention to people).

This design allowed us to:

- (1) Determine whether target pictures elicit a larger LPP than nontargets, when the identical stimulus serves in both conditions. In many previous categorization studies (e.g., Codispoti, Ferrari, Junghöfer, et al., 2006; Batty & Taylor, 2002; Antal et al., 2000), different stimuli served as targets and nontargets, making it difficult to disentangle the contribution to the ERP of directed attention and specific picture content. Moreover, in several previous ERP categorization studies (Codispoti, Ferrari, Junghöfer, et al., 2006; De Cesarei et al., 2006; Batty & Taylor, 2002; Antal et al., 2000), target pictures were always animals. Because pictures of animals are typically judged as somewhat more arousing (Bradley & Lang, 2007) than neutral people or objects, it is possible that the larger LPP for target pictures was mediated by emotionality, rather than by directed attention. The current design allows all target/nontarget differences to be interpreted as reflecting directed attention, and not to some intrinsic difference for the target pictures.
- (2) Determine whether the LPP is modulated by the emotional content of the pictures when participants are engaged in an unrelated categorization task. In general, the heightened LPP found when viewing affective pictures is a robust phenomenon. On the other hand, in the current study, pictures were presented quite briefly (30 msec), and attention was not specifically directed toward affective information. Thus, although we expect larger LPPs for emotional, compared to neutral, pictures in both tasks, these effects may be altered by specific task parameters.
- (3) Determine the relationship between directed and motivated attention in terms of amplitude and topography of the LPP, and to determine whether and to what extent there is an interaction between these two factors during the processing of complex visual stimuli. If top-down (directed) and bottom-up (motivated) processes are independent, the prediction is that these two factors should show additive effects on the LPP.

METHODS

Participants

Participants were 20 students (10 women), ranging in age from 20 to 31 years, from the University of Bologna. Nineteen participants were right-handed. They had normal or corrected-to-normal visual acuity. Informed consent was obtained from each participant before the beginning of the experiment.

Stimuli

Four hundred fifty color pictures were selected from various sources, including the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005), public domain pictures available on the Internet, and from document scanning. Pictures depicted animals ($n = 150$), people ($n = 150$), or inanimate scenes (objects and landscapes, $n = 150$: for ease of presentation, we will refer to this stimulus category as “objects”). For people, pictures varied in affective content, depicting either erotic couples ($n = 50$), neutral people ($n = 50$), or mutilated bodies ($n = 50$). Stimuli were presented on a 19-in. CRT monitor, at 1024×768 pixel resolution and 100 Hz refresh rate, subtending 14.25° horizontal by 10.47° vertical of visual angle. Sixteen different presentation sequences were built by permuting image order with the constraint that no more of three consecutive images depicting the same content were presented.

Design and Procedure

Two visual categorization tasks—either animal or human—were performed by each participant in two separate sessions (one week apart). For the animal task, participants were instructed to press one button if the picture contained an animal and another if it did not. For the human task, participants were asked to press one button if the picture contained a human and another if it did not. In each task, subjects were asked to press one of two buttons with the index or middle finger of the dominant hand, indicating whether the presented image contained the target category or not. Half of the participants performed the animal task in the first session and then the human task in the second session; the

order was reversed for the other half. The same set of pictures was viewed in each session.

Participants sat in a comfortable chair, at a distance of 1.5 m from the computer monitor. Each experimental session was divided into four blocks, each containing the same 450 pictures presented with a different order. The pictures were flashed for 30 msec, followed by a black screen which lasted between 2500 and 3000 msec (intertrial interval).

EEG Recording and Processing

Electroencephalogram (EEG) was recorded at 500 Hz using a 59-channel ElectroCap, an SA Instrumentation (San Diego, CA) UF-64/72BA amplifier and in-house-developed acquisition software. Impedance of each sensor was kept below 10 k Ω . EEG was recorded from 59 active sites referenced to Cz, on-line filtered from 0.01 to 100 Hz. Vertical and horizontal eye movements were recorded using silver/silver chloride miniature electrodes. Off-line analysis was performed using EMEGS (Junghöfer & Peyk, 2004) and included correction of eye movements from the EEG signal (Miller, Gratton, & Yee, 1988), low-pass filtering at 30 Hz, artifact detection, and sensor interpolation (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). Finally, the signal was re-referenced to the average of all channels, and the mean of the 100-msec preceding stimulus onset was subtracted from each waveform. Processed data were averaged separately for each participant, stimulus category, and task condition. The LPP was scored as the average amplitude of the ERP in the 400–600 msec time window over centro-parietal sensor sites (C1, C3, Cz, CP1, CP3, CPz, P1, P3, Pz, C2, C4, CP2, CP4, P2, P4, PO3, POz, PO4). Only trials where participants correctly categorized stimuli were analyzed.

Behavioral Variables

Reaction time (RT) and accuracy were collected using PST E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Analysis of RT was performed only for correct trials.

RESULTS

Late Positive Potential

Figure 1 illustrates the ERPs elicited when processing target and nontarget pictures, averaged over task, and illustrates a clear difference in the late positive component over centro-parietal sensors. A two-way analysis of variance (ANOVA) was conducted on the mean in the 400–600 window with two repeated measures of task relevance (2: target, nontarget) and picture content (2: animal, people) in order to first investigate the effects of directed attention on the modulation of the LPP. Fig-

ure 2 presents waveforms averaged over centro-parietal sensors as a function of picture content (animal and people) and task relevance.

As shown in Figure 2, heightened positivity was systematically obtained for target, compared to nontarget, stimuli when either animals [$F(1, 19) = 10.4, p < .005, \eta^2 = .35$] or people [$F(1, 19) = 10.8, p < .005, \eta^2 = .36$] were task-relevant. The magnitude of the increase in positivity for targets, compared to nontargets, was equivalent in both tasks (interaction *ns*, $F < 1$), indicating that the effect of directed attention on the LPP modulation did not vary with the specific content of the target picture.

Table 1 lists the LPP magnitude for each of the picture contents in each task. In general, pictures of people (emotional and neutral) showed a larger LPP compared to pictures of animals [$F(1, 19) = 4.75, p < .05, \eta^2 = .2$]. This effect disappeared, however, when animals were compared only to neutral people, suggesting the heightened LPP was mainly related to pictures of emotional people. In fact, pictures of animals showed an overall larger LPP, compared either to viewing objects or neutral people [$F_s(1, 19) > 75, p < .0001, \eta^2 > .7$], and the LPP when viewing neutral people was also larger than when viewing objects [$F(1, 19) = 26.6, p < .0001, \eta^2 > .6$].

In order to investigate effects of both directed and motivated attention on the LPP, a two-way ANOVA was performed on ERPs measured when viewing pictures of people, using repeated measures of task relevance (2: target, nontarget) and picture content (3: pleasant, neutral and unpleasant). Figure 3 (top) illustrates the mean (400–600 msec) LPP amplitude for pleasant, neutral, and unpleasant pictures when they were targets (human task) or nontargets (animal task). Again, a main effect of task relevance [$F(1, 19) = 10.88, p < .005, \eta^2 = .36$] indicated greater positivity for targets, compared to nontargets, with larger LPPs for pictures of people when they were targets (i.e., human task) compared to when they were nontargets (i.e., animal task). On the other hand, in both tasks, the LPP was modulated by picture emotionality [$F(2, 38) = 57.65, \eta^2 = .75$, for animal task; $F(2, 38) = 38.56, \eta^2 = .67$ for human task], with pleasant and unpleasant pictures eliciting larger LPPs than neutral pictures ($p_s < .0001$). In this study, pleasant pictures also elicited somewhat more positivity than unpleasant pictures [$F_s(1, 19) > 15.57, p < .001, \eta^2 > .45$].

Figure 3 (bottom) illustrates the grand-average ERPs for emotional (pleasant and unpleasant averaged together) and neutral pictures when they were targets (human task) or nontargets (animal task), and illustrates that the differential positivity between pictures of emotional and neutral people was equivalent regardless of task relevance (interaction *ns*, $F < 1$). Thus, the amount of heightened cortical positivity elicited when pictures were targets was equivalent for both emotional and neutral pictures. A comparison of the magnitude of LPP modulation as a function of directed attention (i.e., target minus nontarget) and of

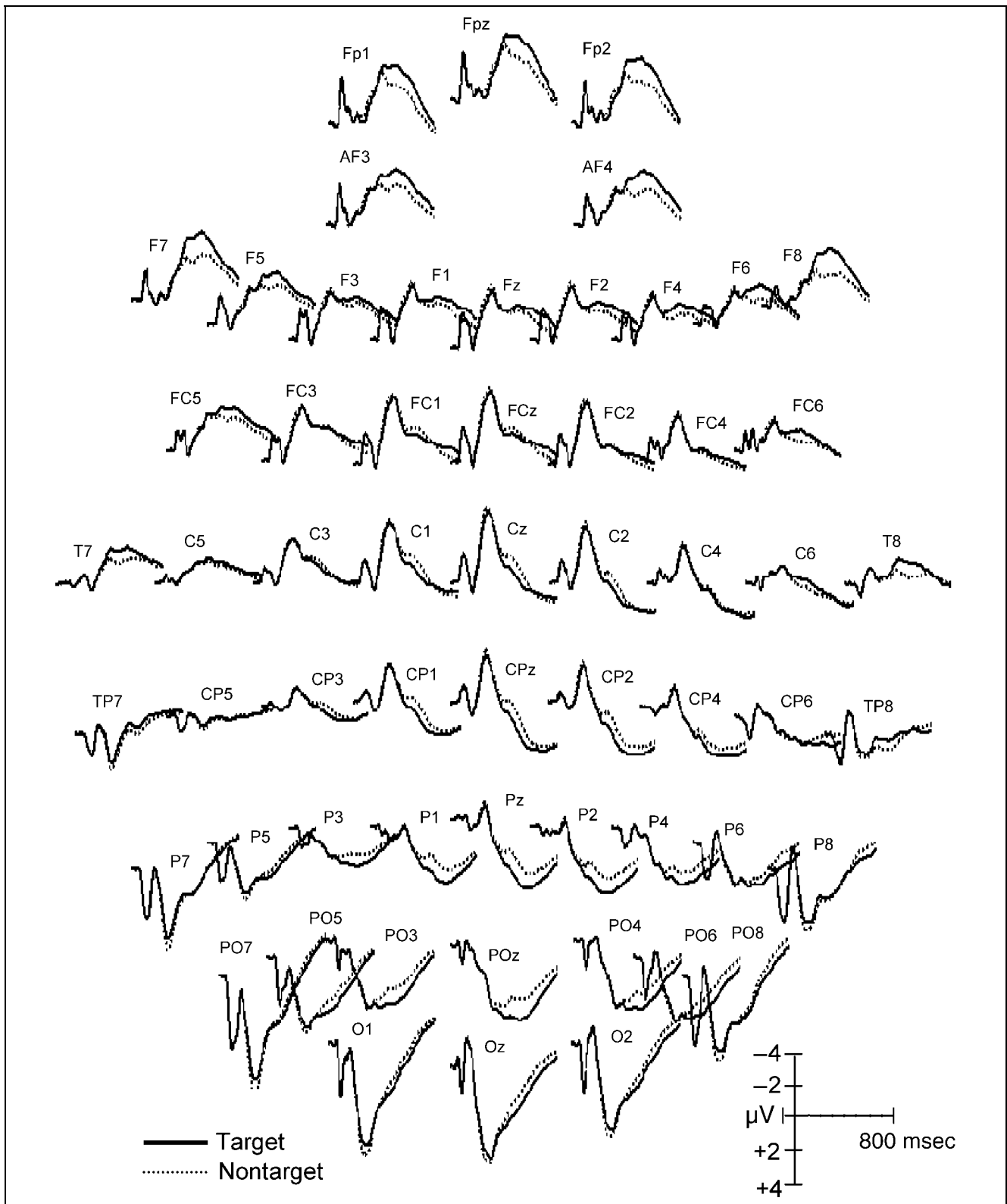


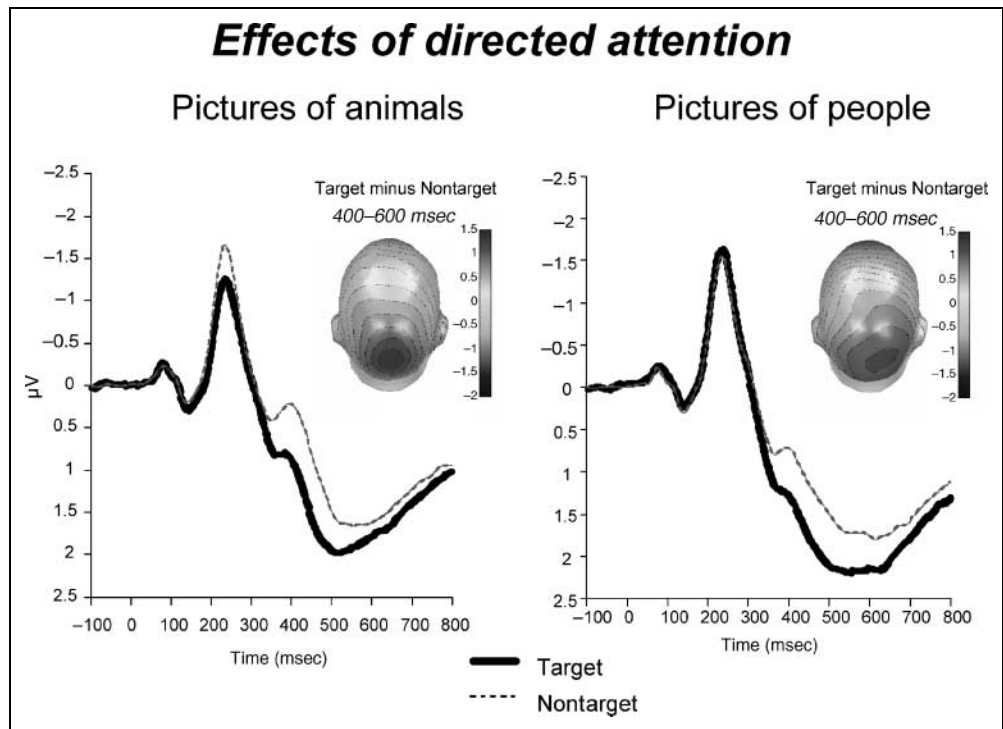
Figure 1. Grand-averaged ERP waveforms for targets (thick line) and nontargets (dotted line), averaged over task. Negative is plotted up and frontal electrodes are shown at the top of the figure.

motivated attention (i.e., emotional minus neutral) indicated that the LPP change prompted by the emotional content of the pictures was almost twice the magnitude of the positivity elicited between targets and nontargets in

the directed attention condition [$F(1, 19) = 9.3, p < .01, \eta^2 = .33$; see insert in Figure 3].

An analysis involving laterality (left and right hemispheres, excluding midline sensors) showed an overall

Figure 2. Left: Grand-average ERP waveforms from centro-parietal sites for pictures of animals when they were targets (animal task) or nontargets (people task). Inset shows the top view of the scalp distribution of the difference in positivity in the 400–600 msec between target and nontarget picture processing. Right: Grand-average ERP waveforms from centro-parietal sites for pictures of people when they were targets (people task) or nontargets (animal task). Inset shows the top view of the scalp distribution of the difference in positivity in the 400–600 msec between target and nontarget picture processing.



larger positivity over the right hemisphere [$F(1, 19) = 35.48, p < .0001, \eta^2 = .65$], without any interactions involving either task relevance or picture content.

Behavioral Data

Table 1 lists the RT and accuracy data as a function of task and picture content.

Reaction Times

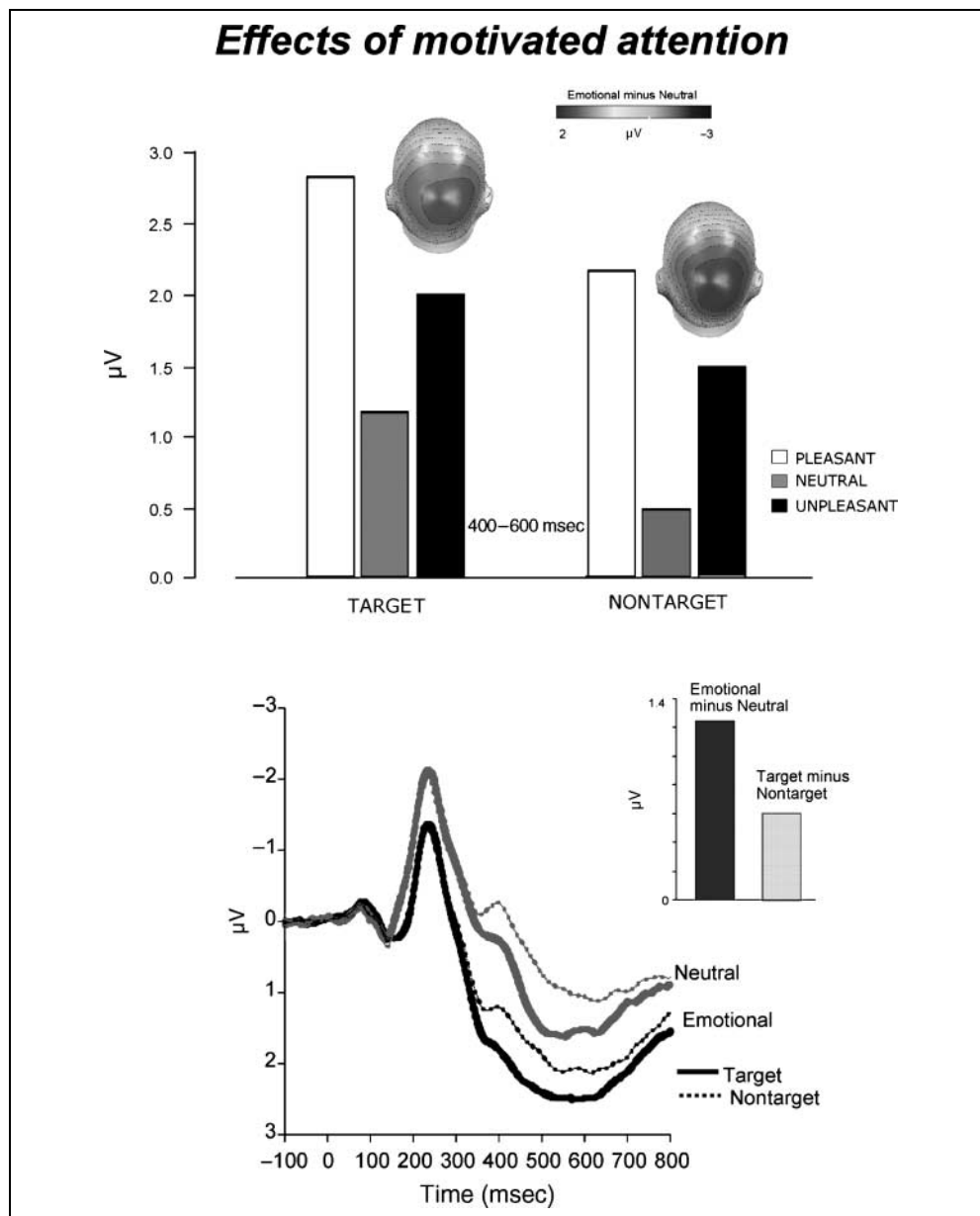
A 2 (task relevance: target, nontarget) \times 2 (picture content: animal, people) ANOVA indicated that RTs were slower to target stimuli compared to nontargets [$F(1, 19) = 5.43, p < .05, \eta^2 = .22$], regardless of whether targets were animals or humans.

For pictures of people, a Task relevance (2: target, nontarget) \times Picture content (3) ANOVA revealed a significant interaction [$F(2, 38) = 20.62, p < .0001, \eta^2 = .52$], indicating that the effect of the emotional content was different depending on the target status of the pictures. When people were targets, participants were faster to categorize erotica, compared to either pictures of neutral or mutilated people [$F_s(1, 19) > 14.85, p_s < .005, \eta^2 > .44$], and were slightly faster deciding that neutral people, compared to mutilations, were people as well [$F(1, 19) = 6.06, p < .05, \eta^2 = .24$]. On the other hand, when people were nontargets (animal task), RTs to pictures showed a quadratic trend with slower RTs to pleasant and unpleasant pictures compared to neutral stimuli [$F_s(1, 19) > 25, p < .0001, \eta^2 = .57$]. No significant difference was found between pleasant and unpleasant pictures ($p > .05$).

Table 1. Means (Standard Errors) of Late Positive Potential (LPP, μ V), Response Times (RTs, msec), and Accuracy (% Correct) for Each Stimulus Category and Task

	<i>Animal Task</i>			<i>Human Task</i>		
	<i>LPP</i>	<i>RT</i>	<i>Accuracy</i>	<i>LPP</i>	<i>RT</i>	<i>Accuracy</i>
Animal	1.84 (.29)	770 (20)	95 (.7)	1.25 (.22)	710 (19)	95 (2.5)
Pleasant people	2.24 (.29)	767 (26)	98 (.3)	2.88 (.32)	731 (24)	95 (2.6)
Neutral people	0.57 (.23)	726 (19)	98 (.3)	1.29 (.28)	753 (26)	92 (2.7)
Unpleasant people	1.57 (.28)	790 (26)	95 (.7)	2.01 (.33)	769 (22)	90 (1.6)
Object	0.58 (.24)	727 (19)	97 (.3)	0.69 (.21)	682 (19)	99 (0.5)

Figure 3. Top: Mean LPP over centro-parietal sensors for pleasant, neutral, and unpleasant pictures when they were targets or nontargets, and the scalp topography (top view) of the difference in positivity in the 400–600 msec window between emotional and neutral pictures when they were targets (people task) or nontargets (animal task). Bottom: Grand-average ERP waveforms from centro-parietal sites for emotional (pleasant and unpleasant averaged together) and neutral pictures of people when they were targets (people task) and when they were nontargets (animal task). Inset shows the mean difference in the LPP between emotional and neutral stimuli, and between target and nontarget people.



Accuracy

The overall accuracy in both tasks was quite high (average 95.7%), however, participants were less accurate for target than for nontarget stimuli [$F(1, 19) = 26.69, p < .0001, \eta^2 = .58$]. Accuracy was also affected by affective picture content (main effect [$F(1, 19) = 28.87, p < .0001, \eta^2 = .6$], with unpleasant pictures generally associated with a higher error rate overall, compared to pictures of neutral people, which, in turn, were associated with a higher error rate than pleasant pictures.

DISCUSSION

The LPP is clearly affected by directed attention during the categorization of natural scenes: Briefly presented

pictures elicited larger LPPs when they were targets, compared to when they were nontargets, regardless of the specific task, supporting the hypothesis that the LPP is specifically modulated by directed attention. Although previous studies using briefly presented natural scenes have reported larger LPPs for target compared to nontarget stimuli (Codispoti, Ferrari, Junghöfer, et al., 2006; Batty & Taylor, 2002; Antal et al., 2000), different exemplars consistently served in the target and nontarget conditions, making it difficult to disentangle the contribution of directed attention from specific picture content. The fact that, in the present study, the identical pictures prompted a heightened LPP magnitude when they served as targets strongly supports the idea that the LPP reflects attentional capacity invested in categorization of task relevant events (Kok, 2001). These data

corroborate the astonishing human capacity to process the meaning of natural images in severely impoverished visual conditions (Grill-Spector & Kanwisher, 2005; Van Rullen & Koch, 2003; Keysers, Xiao, Földiák, & Perrett, 2001; Van Rullen & Thorpe, 2001), as categorization was quite good despite a brief 30-msec presentation.

Pictures of animals, whether they were targets or nontargets, prompted somewhat greater positivity than pictures of neutral people or objects. A similar effect is found during passive viewing of these pictures (Cardinale, Ferrari, De Cesarei, Biondi, & Codispoti, 2005), which is consistent with the fact that pictures of (nonattacking) animals are generally rated as somewhat more arousing than other neutral pictures (Bradley & Lang, 2007), leading to a slightly larger LPP. On the other hand, the LPP was further enhanced when animal pictures were targets, compared to when they were nontargets, even when the same individual processed the same picture in either the task-relevant or non-task-relevant context. These data clearly indicate that directed attention modulates the magnitude of the LPP measured over centro-parietal sensors.

Similar to task-relevant stimuli, inherently significant (emotional) pictures elicited a larger LPP, compared to affectively neutral pictures, despite the fact that participants were engaged in an affectively unrelated categorization task, and picture stimuli were presented for a mere 30 msec. These findings further suggest that affective modulation of the LPP is not dependent on intentional evaluation of the stimulus hedonic content but may reflect an obligatory process that occurs regardless of the specific task instructions, at least in conditions in which the task requires semantic processing (see Pessoa, Padmala, & Morland, 2005, and Pessoa, McKenna, Gutierrez, & Ungerleider, 2002, for different results).

Taken together, the present findings indicate that whether a visual stimulus is task-relevant (target) or is simply affectively engaging, similar cortical differences, as measured by ERPs, are found over centro-parietal sensors. Effects of directed and motivated attention on the LPP appeared to be additive, with the greatest positivity found for emotional pictures that were targets of directed attention, and the least for neutral pictures that were nontargets.

Additive effects of two factors are often interpreted as evidence that each factor affects a different process (Sternberg, 1969, 2001). Thus, one interpretation of the data is that the amplitude of the LPP reflects the operation of two separate processes in task-relevant and emotional contexts. Because the LPP has multiple generators, and occurs over several hundred of milliseconds, it is certainly possible that motivated and directed attention utilize different neural generators, both of which contribute to the amplitude of the LPP. For instance, using functional magnetic resonance imaging, Fichtenholtz et al. (2004) found that specific brain structures were differentially sensitive to task relevance and

emotion, with a dorsal network active in task-relevant contexts and a ventral circuit involved in processing emotionally salient stimuli. Both networks were active when participants were asked to count aversive pictures as targets.

On the other hand, it is also possible that the LPP reflects the operation of a neural circuit, attentional in nature, that is utilized in both contexts. According to this hypothesis, the LPP reflects the amount of attentional resources allocated to either top-down or bottom-up processes, with each process incrementing activity in similar neural circuits. Consistent with this interpretation, Yamasaki, LaBar, and McCarthy (2002) found that limbic structures such as the anterior cingulate gyrus (ACG) showed equivalent activation for task-relevant stimuli (circles) and aversive distractors. Because scalp-recorded LPPs are hypothesized to be generated in networks that involve the anterior cingulate (Kok, 2001), it is possible that the LPP reflects, at least in part, ACG activity and that this structure is involved in the allocation of resources in both directed and motivated attention. Given the differences in the temporal resolution of the two techniques (ERP and functional magnetic resonance imaging) and the fact that the LPP can reflect multiple neural generators, further studies are needed to clarify the neural structures involved in attention and emotion.

Although there was no interaction between task relevance and emotion in the current study, it is possible that explicitly directing attention toward an emotional dimension of the stimuli might enhance the processing of emotional picture content, prompting larger LPP affective modulation in a task context (Schupp et al., 2007). Some recent neuroimaging studies (Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003; Keightley et al., 2003; Lane, Fink, Chau, & Dolan, 1997) have reported increased activity in limbic regions (including ACG and the amygdala) when the task focused on affective, compared to non-affective, features. Most of these studies did not include neutral pictures, however, making it difficult to evaluate effects of the task on emotional modulation, which can only be assessed as a difference in processing between emotional and neutral stimuli.

In the current study, RT to pictures that were targets was slower than for nontargets, whereas RT is typically faster for targets in many categorization tasks (Codispoti, Ferrari, Junghöfer, et al., 2006; De Cesarei et al., 2006; Kincses, Chadaide, Varga, Antal, & Paulus, 2006; Antal et al., 2000, 2003; Johnson & Olshausen, 2003). One possibility is that, in both tasks (animal or human), there were many nontarget stimuli that shared perceptual features with the target (animate features such as eyes, legs, etc.), making the decision regarding targets more difficult. Consistent with this, previous studies have found longer RTs when nontargets share features with the targets, compared to when nontargets are dissimilar (Azizian et al., 2006; Hodsoll, Humphreys, & Braithwaite, 2006),

suggesting that target classification requires more effort when perceptually similar nontargets are part of the array (Evans & Treisman, 2005).

Taken together, the present findings provide information regarding the relationship between motivated and directed attention. Both task relevance and emotional-ity heightened LPP amplitude, with the largest LPPs for task-relevant emotional pictures. In our view, stimuli that garnered heightened attention were originally those that supported or threatened the life of the individual and species, including appetitive stimuli, such as food and sexual partners, and aversive stimuli, such as predators and other threatening stimuli (Lang et al., 1997). Neural circuits evolved that supported the heightened resource allocation necessary for sensory/perceptual processing and for determining appropriate actions in these motivationally relevant contexts. It is possible that so-called cold cognitive processes utilize the same attentional circuits that evolved to respond rapidly to affective stimuli, with the result that motivationally relevant and task-relevant cues now show similar electrocortical patterns.

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