Cross-modal attention capture by affective stimuli: Evidence from event-related potentials

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The P3 component of the event-related potential (ERP) to an acoustic startle probe is modulated during picture viewing, with reduced P3 amplitude when participants view either pleasant or unpleasant, as opposed to neutral, pictures. We have interpreted this as reflecting capture of attentional resources by affective pictures, with fewer resources available for processing the secondary startle probe. In the present study, we tested this resource allocation hypothesis by presenting either pictures or sounds as foreground stimuli, with the prediction that P3 amplitude in response to secondary startle probes would be reduced for affectively engaging foregrounds regardless of modality. Using dense-array electroencephalography and a source estimation procedure, we observed that P3 amplitude was indeed smaller when startle probes were presented during emotional, as opposed to neutral, stimuli for both sound and picture foregrounds. Source modeling indicated a common frontocentral maximum of P3 modulation by affect. The data support the notion that emotionally arousing stimuli transmodally attract resources, leading to optimized processing of the affective stimuli at the cost of the processing of concurrent stimuli.

The abrupt presentation of a brief intense acoustic stimulus (e.g., a burst of white noise) elicits a reflexive startle response that is modulated by emotion. One component of the startle response—the reflexive eyeblink—is modulated by hedonic valence, with larger eyeblinks elicited when participants view unpleasant pictures, and smaller blinks when they process pleasant stimuli. On the other hand, the electrocortical response to the same startling probe varies with emotional arousal, rather than with hedonic valence: The amplitude of the P3 component of the event-related potential (ERP) is smaller when participants view either pleasant or unpleasant, as opposed to neutral, pictures (Cuthbert, Schupp, Bradley, McManis, & Lang, 1998; Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997; Schupp et al., 2004). This pattern of results has been interpreted as reflecting reduced availability of resources for processing the startle probe in the presence of affectively arousing, as opposed to neutral, pictures. The affectively arousing foreground stimuli effectively capture attentional resources from a limited-capacity system.

This interpretation is consistent with reports of amplified electrocortical processing for affectively engaging visual stimuli at early (Junghöfer, Bradley, Elbert, & Lang, 2001; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) and late (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Keil et al., 2002) latencies. Electrocortical evidence for a limited-capacity attention system is also abundant. Researchers using P3 as a marker for attentional involve-

ment in a primary task have reported that the auditory ERP tends to be diminished if the auditory stimulus eliciting the P3 is accompanied by a task-irrelevant visual stimulus, in comparison with what is found when the auditory stimulus is presented alone (Oray, Lu, & Dawson, 2002).

Resource allocation during emotional processing can be studied by using the P3 component of the ERP that occurs in response to the secondary startle probe. The P3 is a positive deflection of the ERP, which is observed in response to task-relevant stimuli, and it is also present in response to novel or infrequent stimuli (Kok, 2001; Linden, 2005). Extensive work with this measure has yielded a complex database suggesting that P3 has several overlapping subcomponents, depending on aspects of the stimulus eliciting the P3 component (e.g., a novel or a rare stimulus), and on the type of task used. For the present purpose, studies of so-called novelty P3 (also referred to as P3a; see Simons, Graham, Miller, & Chen, 2001) are of particular interest. This component has been related to more automatic detection of rare or novel and relevant events and has been linked to generator structures in the frontal cortex (Dien, Spencer, & Donchin, 2003).

We have suggested that P3 modulation in the context of affective picture processing reflects motivated attention, in which stimuli that activate fundamental defensive or appetitive neural systems prompt an increase in orienting and attentional resource allocation (Lang, Bradley, & Cuthbert, 1997). In line with that notion, enhancements of

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P3 during affective picture viewing have been observed in a number of studies, suggesting increased resource allocation to emotionally engaging stimuli (Cuthbert et al., 2000; Keil et al., 2002). Conversely, the P3 response to an acoustic startle probe presented during picture viewing shows the opposite pattern, with smaller probe P3 responses when participants concurrently view emotional, as opposed to neutral, pictures (Cuthbert et al., 1998; Schupp et al., 2004). That is, because motivationally relevant pictures utilize greater attentional resources than do neutral pictures, fewer are available for processing the startle probes. Probe P3 amplitude is thus interpreted as indexing resource allocation for the processing of emotional stimuli.

In the present study, we examined the P3 response to secondary startle probes presented while participants either viewed affective pictures or listened to affective sounds. In both groups of participants, we measured the P3 to an acoustic startle probe delivered during looking or listening. To increase the sensitivity to emotion-related changes in topographical distribution of P3, we used a dense sensor array (129 channels). We compared ERP amplitudes in the P3 range for startle probe processing when participants looked at pictures and listened to sounds, and also conducted source strength analyses, using a linear projection method, the minimum norm estimate (Hauk, Keil, Elbert, & Müller, 2002), to examine possible neural sources of affective modulation of probe P3.

We expected to replicate our previous finding of reduced P3 amplitude during affective picture viewing (Cuthbert et al., 1998), and further, to identify neural structures underlying this effect using the minimum norm source estimation approach. A more central research question concerns whether acoustic probe P3 modulation will be similar when the foreground modalities differ. Several studies have suggested that allocation of attentional resources may occur in a modality-specific manner under some circumstances (see Lipp & Neumann, 2004), facilitating subsequent processing in the same modality (e.g., Schmitt, Postma, & De Haan, 2000). In this type of framework, attentive processing of motivationally relevant sounds should increase P3 amplitude elicited by the auditory startle probe, because resources would be allocated to the auditory modality. Interpretation of the reduction of auditory startle probe P3 for emotionally arousing visual foregrounds in this perspective would be due to increasing transfer to the visual modality at the cost of resources available for auditory processes.

In contrast, if motivated attention is allocated in a supramodal, central fashion, the amplitude of P3 to an acoustic startle probe should be similarly modulated during processing of affective stimuli, regardless of the presentation modality of the emotional foreground (i.e., auditory or visual). Here, we drew on the concept of motivated attention as a process that enhances adaptive behaviors in the presence of stimuli that threaten or sustain life (Lang et al., 1997). Thus, we expected similarly reduced P3 amplitudes to the startle probe, regardless of whether participants were viewing emotional pictures or were listening to affective sounds.

METHOD

Participants

A total of 42 students taking the General Psychology course at the University of Florida participated as part of a course requirement after giving informed consent. The study was approved by the University of Florida institutional review board. Twenty-three students (10 female, 13 male) listened to sounds, and 19 students (8 female, 3 male, 8 inadvertently not coded) viewed pictures.

Stimuli and Design

Visual foreground: Looking at pictures. Sixty pictures¹ were selected from the International Affective Picture System (IAPS; Bradley, Cuthbert, & Lang, 2005), a collection of photographs that vary in affect, to include 20 pleasant (mean pleasure, arousal = 7.3, 5.4), 20 neutral (mean pleasure, arousal = 4.9, 2.8), and 20 unpleasant (mean pleasure, arousal = 2.3, 6.9) pictures. Unpleasant and pleasant pictures were significantly more arousing than neutral pictures, and unpleasant pictures prompted slightly higher arousal ratings than did pleasant pictures. The screen was placed 1.5 m in front of the viewer, resulting in a picture presentation with a visual angle of about 18° horizontally and 10° vertically. Each picture was presented for 1,500 msec, followed by a 3.5-sec intertrial interval. Shorter presentation times in comparison with those for sounds (see below) were used to reduce the amount of exploratory eye movements during picture viewing, which would have resulted in loss of trials for subsequent analyses. To compensate for total study time, each set of 60 pictures was presented four times. Startle probes were 95 dB(A) bursts of white noise, delivered 1,100 msec after picture onset on 20 trials for each picture valence. The interprobe interval varied from 9 to 22 sec, with a mean of 15 sec.

Auditory foreground: Listening to sounds. Sixty 6-sec sounds² were selected from the International Affective Digitized Sounds (IADS; Bradley & Lang, 1999), a collection of acoustic stimuli that vary in affect, to include 20 pleasant (mean pleasure, arousal = 7.0, 5.9), 20 neutral (mean pleasure, arousal = 5.0, 4.7), and 20 unpleasant (mean pleasure, arousal = 2.4, 7.5) sounds. As with the picture stimuli, the unpleasant and pleasant sounds were significantly more arousing than the neutral sounds, and the unpleasant sounds prompted slightly higher arousal ratings than did the pleasant sounds. Each sound stimulus was presented twice during the experiment, with a duration of 6 sec and an intertrial interval that varied from 8 to 18 sec. The acoustic startle probes were presented on 20 trials for each sound valence at 3–4.5 sec after sound onset.

Electrophysiological Recordings

EEG was recorded continuously from 129 electrodes using an Electrical Geodesics (EGI) EEG system and digitized at a rate of 250 Hz, using Cz as a recording reference. Impedances were kept below 50 k Ω , as recommended for the Electrical Geodesics high input impedance amplifiers. A subset of EGI net electrodes located at the outer canthi as well as above and below the right eye was used to determine horizontal and vertical electrooculogram (EOG). All channels were preprocessed online by means of 0.1-Hz high-pass and 100-Hz low-pass filtering.

Procedure

Data reduction and analysis. Epochs of 600 msec (150 msec prestartle, 450 msec poststartle) were obtained for each startle probe from the continuously recorded EEG, relative to probe onset. The mean voltage of a 120-msec segment preceding startle probe onset was subtracted as the baseline. In a first step, data were low-pass filtered at a frequency of 50 Hz (24 dB/octave) and then submitted to the procedure proposed by Junghöfer, Elbert, Tucker, and Rockstroh (2000), in which statistical parameters exclude channels and trials contaminated with artifacts. Because the startle probe reliably elicited eyeblinks from 60 to 120 msec poststimulus, an interval ranging from 190 to 450 msec poststartle was used for artifact cor-

Table 1
Regional Voltage Means (With Standard Deviations) at Site Pz and Eight Immediate Neighbor Electrodes in a Window From 260 to 340 msec Following Presentation of an Acoustic Startle Probe

	Pleasant		Neutral		Unpleasant	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Pictures	3.06	3.30	4.91	3.66	3.27	3.19
Sounds	4.66	2.46	5.83	3.12	4.31	2.61

rection. This procedure resulted in rejection of trials contaminated with artifacts (including ocular artifacts) outside the critical blink interval. Artifacts other than blinks lying within the startle interval were evaluated by visual inspection, and the respective trials were rejected. Recording artifacts were first detected using the recording reference (i.e., Cz). Subsequently, global artifacts were detected using the average reference, and distinct sensors from particular trials were removed interactively, on the basis of the distribution of their mean amplitude, standard deviation, and maximum slope. Data at eliminated electrodes were replaced with a statistically weighted spherical spline interpolation from the full channel set. The mean number of approximated channels across conditions and subjects was 9. With respect to the spatial arrangement of the approximated sensors, it was ensured that the rejected sensors were not located within one region of the scalp, because that would make interpolation for this area invalid. Spherical spline interpolation was used throughout, both for approximation of sensors and for illustration of voltage maps (Junghöfer, Elbert, Leiderer, Berg, & Rockstroh, 1997).

Single epochs with excessive eye movements and eyeblinks or more than 20 channels containing artifacts in the time interval of interest were discarded. The validity of this procedure was further tested by visually inspection of the vertical and horizontal EOG as computed from a subset of the electrodes that were part of the electrode net. Subsequently, data were arithmetically transformed to the average reference, which was used for all analyses. After artifact correction, an average of 74% of the trials were retained in the analyses, with a mean of 14.9 (range, 11–18) trials for the pleasant foregrounds, 14.5 (range, 12–17) for the neutral foregrounds, and 13.9 (range, 10–19) for the unpleasant foregrounds. No difference in trial number was observed between foreground modalities or affective categories (all $F_s < 2.0$, $p_s > .40$).

Scoring of P3 amplitude: Regional mean analysis. For a first statistical analysis of the P3 component, we scored the mean voltage in a time window ranging from 260 to 340 msec for each participant and condition in each experiment. This latency range is consistent with the majority of studies of P3 using infrequent, salient stimuli (see, e.g., Opitz, Mecklinger, Friederici, & von Cramon, 1999) such as the startle probes in the present study. Given the low trial count, we did not execute a more fine-grained temporal analysis, but relied on the robustness of the P3 wave in the indicated time range. As can be seen in Figures 1 and 2, the P3 in the latency range of interest was most pronounced at sensors surrounding site Pz. Thus, we selected Pz as well as eight immediate neighbor electrodes to form a regional mean as a measure for overall effects of conditions on P3 amplitude.

These values were determined for each foreground content and participant and were submitted to repeated measures ANOVAs. Separate ANOVAs with one within-subjects factor of hedonic valence were conducted for visual foregrounds (pleasant, neutral, unpleasant) and acoustic foregrounds (pleasant, neutral, unpleasant tone). Where appropriate, degrees of freedom were corrected by means of the Greenhouse–Geisser method, and corrected p values are reported together with uncorrected degrees of freedom. Significant effects were followed by contrast analysis examining the presence of the expected quadratic trend in the voltage data—that is, the find-

Figure 1. Startle probe ERPs at three midline electrodes for the viewing of pleasant, neutral, or unpleasant pictures. ERPs are shown at three midline electrodes for pleasant, neutral, and unpleasant foreground pictures. The gray shaded region indicates the time segment used for statistical analysis. Averages reflect 19 participants.

ing that startle P3 amplitude for emotional (pleasant or unpleasant) foregrounds was less than for neutral pictures.

Source Space Analyses

To achieve a signal representation reflecting the high spatial resolution of the dense array ERP data, we transformed the individual ERPs into a four-shell spherical source space, using the minimum (L2) norm estimate (MNE) distributed source algorithm (Hämäläinen & Ilmoniemi, 1984; Hauk et al., 2002). This procedure does not allow precise anatomical localization but, in comparison with the use of voltage data, markedly improves spatial specificity (Hauk, 2004). To this end, the voltage data were projected to a source space consisting of 655 evenly distributed dipoles with three orthogonal orientations at each dipole location. This is achieved by multiplying the pseudoinverse of the lead field matrix L with the data matrix D (Hauk, 2004). The L2 (minimum) norm provides a mathematically unique solution for this equation by minimizing the squared source current. Dipole strength at a given dipole site was obtained as the square root of the sum of squared L2 values for each of the three orientations, for each time point of the data.

Statistical parametric mapping. To enhance spatial resolution of the statistical analysis conducted for regional means, we identified dipole sites showing the hypothesized quadratic trend for dipole strength (pleasant = unpleasant < neutral foreground) by conducting trend tests at each dipole location. Mean P3 dipole density values in the selected time window were subject to trend analyses for the expected quadratic trend, resulting in an F value for each dipole site. Because of the problems associated with multiple significance test-

Figure 2. (A) Event-related potential in response to startle probes presented during listening to pleasant, neutral, or unpleasant sounds. Frontal electrodes are shown at the top of the figure. Waveforms reflect means across 23 participants. **(B)** Startle probe ERPs at three midline electrodes for listening to pleasant, neutral, or unpleasant sounds. The gray shaded region indicates the time segment used for statistical analysis. Averages reflect 23 participants.

ing, p values for this analysis were determined according to the permutation method proposed by Blair and Karniski (e.g., Blair, Morris, Frith, Perrett, & Dolan, 1999). Permutation methods are based on a test distribution that is generated from the actual data set by calculating the test statistic of interest for data randomly shuffled across experimental conditions. Hence, a test distribution emerges that contains realizations of the statistic under the assumption that there is no effect of conditions. The present permutation distributions were based on 8,000 draws for entire topographies (i.e., one draw taking into account 655 dipole locations) and the greatest F value of each draw (i.e., of each topography of permutation-based F values) entered the test distribution. For the present data set, this procedure resulted in critical F values of 4.9 ($p < .05$) and 6.8 ($p < .01$).

RESULTS

ERP Scalp Voltages: Regional Means

The grand mean ERPs to the acoustic startle probe are illustrated when startle probes were presented in the contexts of viewing pictures (Figure 1) and of listening to sounds (Figure 2). Startle probes elicited reliable late positivity in the P3 range, reaching maximum amplitudes from 260 to 340 msec, which is consistent with the findings of earlier studies using abrupt and salient auditory stimuli (Opitz et al., 1999; Simons et al., 2001). Regional means in the time region of interest are listed in Table 1. The grand mean ERP also shows a small P50 and subsequent N1 component in response to the startle probe, which were not a focus of the present investigation. A negativity in the temporal vicinity of P3 that has been reported by, for example, Spencer, Dien, and Donchin (1999) was not observed in the present data set.

Visual foreground: Looking at pictures. Regional means showed the expected pattern of differences related to affective picture content [$F(2,36) = 7.0, p < .01$]. Viewing pleasant or unpleasant pictures resulted in significantly smaller P3 amplitude than did viewing neutral pictures, resulting in a significant quadratic trend [$F(1,18) = 17.4, p < .01$] (see Figure 1).

Auditory foreground: Listening to sounds. Paralleling the results for affective pictures, the amplitude of the acoustic probe P3 was similarly sensitive to foreground sound content [$F(2,44) = 7.2, p < .01$]. Listening to pleasant or unpleasant sounds resulted in significantly smaller P3 amplitude than did listening to neutral sounds, which was again reflected in a significant quadratic trend [$F(1,22) = 15.2, p < .01$] (see Figure 2).

Statistical Parametric Mapping

Figure 3 illustrates the mean dipole density maps in the P3 time range during processing of emotional (pleasant or unpleasant) or neutral sounds (bottom) or pictures (top). Paralleling the ERP voltage results, an attenuation in dipole density is obtained in the probe P3 time segment for the processing of affective stimuli in the foreground—whether pictures or sounds. Source activity in this time range indicated a contribution of frontocentral as well as parietal structures when the probe was presented during listening to sounds. A stronger contribution of frontal regions to the source activity in the P3 range was observed for probe processing during the viewing of pictures, with frontocentral and parietal regions also contributing to the overall signal.

In a next step, we combined the minimum norm estimation approach with permutation tests of quadratic trends at each of 655 dipole locations to enhance spatial resolution of the statistical analyses. Trend analyses (in which pleasant and unpleasant stimuli prompted less probe P3 dipole activity) were conducted at each dipole site, resulting in topographical maps illustrating significant quadratic trends (pleasant = unpleasant < neutral) present in the respective time range and foreground modality.

Visual foregrounds. Dipole sites showing significant ($p_{\text{permut}} < .05$) quadratic trends indicating reduced probe

Figure 3. Grand mean topographical distribution of the minimum norm estimate dipole density for the startle probe P3 during viewing of affective pictures and listening to affective sounds. A top view is shown. Darker shades represent greater dipole density.

P3 reactivity for viewing emotional (pleasant or unpleasant), as opposed to neutral, pictures are shown in Figure 4 (top panel). The effects were widespread, and most pronounced in the left frontotemporal area as well as in frontocentral areas.

Auditory foregrounds. The dipole sites showing significant quadratic trends that indicated less probe P3 activity for listening to affective, as opposed to neutral, stimuli were very similar to the maps obtained for visual processing. Effects were again widespread, with a predominance in bilateral frontotemporal regions and frontocentral areas.

DISCUSSION

Affective modulation of the P3 component in response to an acoustic startle probe was observed in the present study, regardless of whether people were viewing pictures or listening to sounds in the foreground. In each case, the amplitude of the P3 elicited by a concurrently delivered acoustic startle probe was attenuated for the processing of affective, as opposed to looking at or listening to neutral, stimuli. Source localization analyses suggested that these differences were mediated mainly by differential activity in frontocentral as well as temporoparietal areas.

These data are strong evidence against a specific modality-directed attentional effect of P3 modulation during affective picture viewing. Our findings are in line with a more general resource allocation account, in which stimuli that activate defensive or appetitive motivational systems engage greater allocation of attentional resources, irrespective of modality. The interpretation of P3 amplitude as reflecting differential attention or orienting is consistent with the assumption that P3 amplitude reflects attentional capacity allocated to categorization of

task-relevant or salient events (Linden, 2005). Although the interpretation of P3 findings still remains controversial, ERP amplitudes in the P3 range generally tend to be larger for intense (Sugg & Polich, 1995) or task-relevant (Polich & Kok, 1995) stimuli and are modulated by the significance of the stimulus for an observer, even in the absence of a task (Keil et al., 2002).

We have suggested that emotional stimuli prompt “motivated attention,” in which the activation of neural circuits mediating appetite and defense is associated with the capture of attentional resources and the enhanced perceptual processing of motivationally relevant stimuli (Lang et al.,

Figure 4. Statistical topographical maps showing dipole sites with a significant ($p_{\text{permut}} < .05$) quadratic contrast, reflecting enhanced probe P3 amplitude for neutral, as opposed to pleasant and unpleasant, contents, shown separately for pictures and sounds. Significance thresholds were determined using permutation distributions (see the Method section). Dipole sites in dark gray represent a significance level of $p_{\text{permut}} < .05$. Only dipole sites shown in black reached the .01 significance criterion.

1997). A reduced P3 component in response to probe stimuli is consistent with increased orienting and attention to motivationally relevant foregrounds. Thus, the startle probe might be viewed as a secondary task that competes for resources with an implicit primary task—that is, with the processing of the affective stimulus. Manipulating resource demands of a primary task, Wickens, Kramer, Vanasse, and Donchin (1983) indeed demonstrated that P3 elicited by the secondary task stimulus was reduced as a function of attentional resources needed to perform the primary task.

Source estimation analyses in our study suggested sources of the startle P3 in frontocentral regions and around the temporoparietal junction. Activity in these regions is consistent with data from numerous studies employing high-resolution techniques to localize the brain regions contributing to P3. For instance, Linden and his colleagues found metabolic enhancement in supplementary motor areas and the anterior cingulate when contrasting oddball versus standard stimuli in a functional imaging study (Linden et al., 1999). Furthermore, they observed strong blood oxygen level dependent response differences in the supramarginal gyrus, which is consistent with the present temporoparietal sources. Interestingly, these differences were present for both visual and auditory oddball tasks, suggesting a panmodal network for processing aspects of relevant events.

The configuration of anatomical regions involved in target detection is also in line with recent work aiming to localize the generators of novelty-related ERPs in the P3 range by means of spatiotemporal dipole modeling (Dien et al., 2003). Dien et al.'s study suggested different components within the time window used in the present study—namely, the P300 and P3a components—having sources in the temporoparietal junction and the anterior cingulate, respectively. In the present study, we could not disentangle potential overlapping subcomponents, but instead aimed to obtain a reliable measure of resource allocation to the processing of relevant stimuli. More importantly, the present study was designed to examine potential neural generators of P3 modulation as a function of foreground modality and content.

Distributed sources contributing to the overall P3 signal also showed differential source activation that was low for arousing foregrounds and high for neutral foregrounds during probe processing. Significant changes in the underlying sources as a function of foreground content were observed at frontocentral regions near the midline, irrespective of modality. In addition, left areas near the temporoparietal junction showed pronounced modulation of probe processing during either sound or picture content. Although the source projection method used here does not permit firm conclusions regarding functional neuroanatomy, this pattern may reflect differential activity in cingulate and parietal regions, including the supramarginal gyrus. Caution is warranted, however, given the nature of the minimum norm estimation, which favors superficial sources and strongly depends on the signal-to-noise ratio.

Modulations off the midline were more specific to affective foreground modalities. During listening to sounds,

neutral stimuli tended to prompt enhanced dipole strength in bilateral perisylvian cortical regions, again suggesting that these cortical sites were more available for probe processing than when affective sounds constituted the foreground stimuli. This finding appears consistent with a role of auditory cortex for P3 generation, which has been reported several times (see, e.g., Linden et al., 1999; Opitz et al., 1999), but has also been subject to intense debate (Dien et al., 2003). Reduced dipole strength in these modality-specific regions might suggest that the affective foreground depleted resources also from a process related to perceptual analysis.

During looking at pictures, auditory regions showed less modulation by affective content, but frontal modulations were more pronounced than for auditory foreground stimuli. The topography of statistical differences points to a stronger involvement of frontal structures, possibly supplementary motor areas, or the anterior cingulate. Bledowski et al. (2004), in a visual oddball task including “novel” stimuli, estimated the sources of novelty P3 using dipole seeding based on functional imaging data. Their dipole model included sources in the insulae and in frontal cortical areas. It should be noted, however, that engagement of the visual system by a visual foreground prior to presenting an auditory probe such as the startle is substantially different from visual oddball tasks. Further, given the high similarity between auditory and visual P3 sources in other work (Linden et al., 1999), the high degree of similarity between auditory and visual foreground topographies for startle probe P3 can be expected.

Taken together, the data are consistent with the hypothesis that affective modulation of the acoustic startle P3 may reflect differences in the neural resources available for startle probe processing. Fewer resources appear to be available for processing a secondary acoustic probe when affective stimuli comprise the foreground, because the affective foreground stimuli capture more attentional resources. In our view, motivationally relevant stimuli activate neural circuits, primarily subcortical, that are shared across mammalian species and are engaged by events that either sustain or threaten life (Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang, 1995). These circuits prompt increased orienting and attention to foreground stimuli, evidenced by heightened electrocortical potentials for viewing affective, as opposed to neutral, pictures (Cuthbert et al., 2000; Keil et al., 2002; Palomba, Angrilli, & Mini, 1997). In the present study, heightened attention to motivationally relevant stimuli resulted in reduced processing of secondary probe stimuli, reflected in the startle P3. This capture effect is similar for motivational engagement prompted both by affective pictures and by affective sounds. We conclude that motivated attention initiates capture of resources from a limited-capacity attention system that acts to allocate resources in a supramodal fashion.

AUTHOR NOTE

This research was conducted when all of the authors were investigators at the NIMH Center for the Study of Emotion and Attention (CSEA) at the University of Florida. A.K. is now at the University of Konstanz, and M.J. is at the University of Münster. This work was supported in part

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NOTES

1. The numbers of IAPS (Bradley, Cuthbert, & Lang, 2005) pictures used were as follows. Pleasant: 2050, 2070, 2080, 2160, 2165, 2170, 2311, 2340, 2341, 2360, 4650, 4651, 4652, 4658, 4659, 4664, 4666, 4670, 4680, 4690. Neutral: 2190, 2200, 2210, 2230, 2381, 2440, 2480, 2570, 2850, 7002, 7009, 7010, 7020, 7030, 7040, 7080, 7175, 7233, 7235, 9070. Unpleasant: 1050, 1120, 1201, 1300, 1930, 3000, 3010, 3053, 3060, 3071, 3080, 3102, 3110, 3130, 3530, 6260, 6350, 6510, 6540, 9405.

2. The numbers of IADS (Bradley & Lang, 1999) sounds used were as follows. Pleasant: 109, 110, 112, 153, 200, 201, 202, 206, 215, 216, 220, 221, 351, 352, 360, 370, 415, 721, 724, 815. Neutral: 120, 231, 251, 254, 311, 320, 322, 325, 361, 403, 425, 627, 700, 706, 708, 720, 723, 725, 726, 904. Unpleasant: 106, 115, 116, 261, 276, 278, 279, 285, 286, 422, 424, 600, 625, 626, 699, 709, 711, 712, 901, 905.

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