Processing of Emotional Distraction Is Both Automatic and Modulated by Attention: Evidence from an Event-related fMRI Investigation

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Abstract

■ Traditionally, emotional stimuli have been thought to be automatically processed via a bottom–up automatic "capture of attention" mechanism. Recently, this view has been challenged by evidence that emotion processing depends on the availability of attentional resources. Although these two views are not mutually exclusive, direct evidence reconciling them is lacking. One limitation of previous investigations supporting the traditional or competing views is that they have not systematically investigated the impact of emotional charge of task-irrelevant distraction in conjunction with manipulations of attentional demands. Using event-related fMRI, we investigated the nature of emotion–cognition interactions in a perceptual discrimination task with emotional distraction by manipulating both the emotional charge of the distracting information and the demands of the main task.

Our findings show that emotion processing is both automatic and modulated by attention, but emotion and attention were only found to interact when finer assessments of emotional charge (comparison of most vs. least emotional conditions) were considered along with an effective manipulation of processing load (high vs. low). The study also identified brain regions reflecting the detrimental impact of emotional distraction on performance as well as regions involved in coping with such distraction. Activity in the dorsomedial pFC and ventrolateral pFC was linked to a detrimental impact of emotional distraction, whereas the dorsal ACC and lateral occipital cortex were involved in helping with emotional distraction. These findings demonstrate that task-irrelevant emotion processing is subjective to both the emotional content of distraction and the level of attentional demand. ■

INTRODUCTION

Possibly because of their relevance for survival, emotional stimuli can affect how we perceive our environment. For instance, emotion can enhance detection by altering the contrast sensitivity required for nonemotional items to enter awareness (Phelps, Ling, & Carrasco, 2006) and can increase or decrease visual estimates of the surrounding environment (Stefanucci & Proffitt, 2009; Stefanucci & Storbeck, 2009; Schnall, Harber, Stefanucci, & Proffitt, 2008; Stefanucci, Proffitt, Clore, & Parekh, 2008; Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008). Although it is generally accepted that emotional items can capture attention, whether their processing is automatic or depends on available attentional resources is a matter of current debate (Pessoa, 2005; Vuilleumier, 2005; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001). A limitation of previous investigations is that they have not systematically assessed the impact of emotional charge of task-irrelevant distraction in conjunction with manipulations of the attentional demands of the main cognitive tasks. Here, we used fMRI

to investigate the effects of attention and emotional charge manipulations in a perceptual task on processing of task-irrelevant emotional distraction. The main focus was on the neural circuitry underlying the impairing effect of emotional distraction on perceptual processing, and the neural correlates of minimizing the impact of such distraction. Investigation of these issues in healthy participants has implications for understanding maladaptive emotion–cognition interactions occurring in affective disorders.

The Debate: The Traditional versus Competing Views of Emotion and Attention

Currently, the emotion literature presents two main competing views on how emotion and selective attention interact with each other: a traditional view (Vuilleumier et al., 2001) and a competing view (Pessoa, McKenna, et al., 2002). The traditional view proposes that processing of emotional information, especially threatening (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003), is given priority; hence, it occurs automatically and is not limited by the availability of attentional resources (Morris, Ohman, & Dolan, 1999). In contrast, the competing view (Pessoa, Padmala, & Morland, 2005; Pessoa, McKenna, et al., 2002),

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based on Desimone and Duncan's (1995) biased competition model of selective attention, proposes that processing of emotional stimuli requires attentional resources. Thus, according to this view, emotional stimuli compete for neural representation with all stimuli, which suggests a top–down regulation of emotion processing.

Evidence supporting the largely accepted and intuitive view that emotional information is processed automatically shows that emotional stimuli can be detected and processed with increased efficacy and that this privileged processing depends on the amygdala (AMY), a main brain structure associated with emotion processing. For instance, using visual search paradigms, a series of behavioral studies found rapid and accurate detection of schematically depicted threatening faces, presented in a display involving similar distractors. This effect is so-called "face in the crowd," "snake in the grass," or "pop-out" effect (e.g., Ohman, Lundqvist, & Esteves, 2001; Hansen & Hansen, 1988). Also, evidence from AMY patients shows that intact AMY is needed to observe enhancement of attention by emotional stimuli, which eliminate "attentional blinks" during processing of rapidly succeeding stimuli (Anderson & Phelps, 2001). Further supporting the traditional view and the role of the AMY, brain imaging evidence shows that facial stimuli with emotional expressions (e.g., expressing fear) can be processed even in the absence of awareness (Whalen, Rauch, et al., 1998). This and other evidence led to the generally accepted notion that processing of emotional information occurs automatically and does not depend on available attentional resources (Moors & De Houwer, 2001; Ohman, Flykt, & Esteves, 2001; Vuilleumier et al., 2001; Morris et al., 1996, 1999; LeDoux, 1996; Hansen & Hansen, 1988). It is important to note that only relatively recently has the operational definition of automaticity become a primary concern when investigating the automatic nature of cognitive processes. Previously, an exact definition of automaticity was muddled by its role in the cognitive process being investigated (e.g., perception, learning, emotion) and by its many separate but related constituting features (e.g., efficiency, intentionality, controllability, awareness). It is now recognized that the features of automaticity need to be separately examined in order to have a better understanding of the process under investigation (see Moors & De Houwer, 2006, for a comprehensive review). Here, we specifically focus on the efficiency (attentional demand) aspect of automaticity.

Strong brain imaging support for the traditional view comes from an influential fMRI study by Vuilleumier et al. (2001). In this study, attention was manipulated by asking participants to attend either to pairs of houses or faces, which were presented in a four-picture display around a fixation point. The pictures in the house pairs were either identical or different, whereas the faces were either fearful or neutral, and the participants were asked to attend either to houses or faces and to make same/different judgments. Supporting the view that emotion processing occurs automatically and independently of the attentional focus, fMRI results revealed increased AMY activity to the fearful faces regardless of whether they were attended or not. Also consistent with the traditional view, RTs to houses were slower when fearful faces were displayed as distractors.

Although the exact mechanisms that allow for automatic processing of emotional information are not fully understood, extant evidence points to the existence of direct subcortical pathways that reach the AMY independently of the typical cortical connections subserving various sensorial modalities (Vuilleumier, 2005). This is consistent with the evidence that emotional stimuli can also benefit from enhanced processing due to their ability to "capture attention" and reallocate processing resources (Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2006; Adolphs, 2004; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004; Price, 2003; Anderson & Phelps, 2001; LeDoux, 2000). As a result of this "parallel processing" that allows for both automatic, nonconscious, preattentional processing and enhanced, conscious, processing boosted by the engagement of attentional mechanisms, emotional stimuli are processed with increased efficacy.

There are also open questions regarding the validity and generalizability of the traditional view. For instance, although animal studies provided direct evidence for the existence of the above-mentioned subcortical route (LeDoux, 2000), human lesion (Anderson & Phelps, 2001) and neuroimaging (Morris et al., 1999) research has provided only indirect evidence that such a pathway exists in humans. Also, even if the proposed subcortical route exists in humans, there is evidence suggesting top–down attention effects as early as the LGN of the thalamus (O'Connor, Fukui, Pinsk, & Kastner, 2002), suggesting that attention could still act on this suggested subcortical route.

Representative brain imaging evidence supporting the competing view comes from work by Pessoa, McKenna, et al. (2002), which challenged Vuilleumier et al.'s findings, and triggered an interesting debate concerning the role of attention in early emotion processing (compare Pessoa, McKenna, et al., 2002; Vuilleumier et al., 2001). The main methodological criticism raised by Pessoa et al. was that previous studies failed to reveal evidence for modulation of emotion processing by attention because the tasks used were not demanding enough to reduce the availability of processing resources to be engaged by emotional information; hence, the findings supporting the automaticity of emotion processing. To address this limitation, Pessoa et al. devised a more difficult task, in which participants had to fixate on centrally displayed faces (men or women, with fearful or neutral expressions) and either make a gender judgment or specify if two peripherally displayed bars were oriented in the same direction or not. Thus, similar to Vuilleumier et al.'s task, the attentional focus was alternating between stimuli with or without emotional content. As expected, in the gender judgment condition

(attending faces), fearful faces evoked greater response in a network of regions associated with emotion processing, including the AMY. However, this differential activation was not present when participants performed the more difficult peripheral (bar-orientation) task and thus did not attend to faces. Also, there were no differences in RTs related to the fearful expression of the face distractors. Based on these findings, Pessoa et al. concluded that emotional information is differentially processed only when there are sufficient attentional resources that are not exhausted by a demanding concurrent cognitive task. In other words, emotional stimuli can "capture attention" if there are enough attentional resources "to be captured" and not engaged by other tasks at hand.

One possible cause for the continuing debate between the traditional and competing views is the fact that emotional content and task demands were not systematically manipulated within the same study, and thus the studies supporting the traditional view may be criticized for not using challenging enough tasks to deplete attentional resources (Luo et al., 2010; Anderson et al., 2003; Vuilleumier et al., 2001), whereas the studies supporting the competing view can be criticized for not using powerful enough emotional stimuli to "capture" attention (Pourtois, Spinelli, Seeck, & Vuilleumier, 2010; Mitchell et al., 2007; Silvert et al., 2007; Pessoa, 2005; Pessoa, McKenna, et al., 2002). The automaticity or reliance on attention of task-irrelevant emotional processing cannot be fully understood unless the degree of emotional charge and the level of task demands are systematically manipulated within the same task. Hence, the main goal of the present investigation was to better understand the intricate nature of emotion–cognition interactions by manipulating both the emotional charge of distracting information and the demands of the main cognitive task.

It should be noted, however, that the traditional and the competing views concerning emotion processing are not necessarily mutually exclusive, as processing of emotional information can be both automatic and modulated by attention. Typically, the degree of attentional demand necessary to complete a task has been manipulated by varying the size of stimulus array, the stimulus attributes (Lavie, 1995), and the difficulty in discriminating stimulus orientation (Pessoa et al., 2005). However, another way of manipulating the difficulty of information processing is by varying the amount of time information is available to process (Grill-Spector & Kanwisher, 2005). Studies employing the later manipulation point to differences in the processing of emotional stimuli as a function of their exposure duration and show that different stages during the time course of emotion processing may vary in their susceptibility to modulations by attention (Luo et al., 2010; Rotshtein et al., 2010; Smith, 2008), with automatic processing of emotional information occurring only during shorter presentation times (White, 1995). This evidence highlights the complex relationship between emotion, attention and awareness and suggests that the two seem-

ingly opposing views concerning basic emotion processing may in fact not be mutually exclusive—i.e., depending on the circumstances emotional information can be processed automatically but can also benefit from engaging available attentional resources. However, to our knowledge, the effect of stimulus duration on task-irrelevant emotional distraction under varying degrees of perceptual load has not been investigated. Such an investigation can provide a possible understanding of the time course of emotion processing that could reconcile the two opposing views.

Elucidation of these matters depends on investigation of the neural correlates of emotion–cognition interactions in conditions where emotional and cognitive processing are in competition with each other. In addition to AMY, a number of other brain regions have been identified as being part of an emotion processing network, including lateral and medial pFC (mPFC) regions, ACC, as well as other brain regions susceptible to emotional modulation (e.g., perceptual areas, such as visual cortex) (Dolcos, Iordan, & Dolcos, 2011; Sabatini et al., 2009; Kober et al., 2008; Dolcos & McCarthy, 2006; Grimm et al., 2006; Wang, McCarthy, Song, & Labar, 2005; Anders, Lotze, Erb, Grodd, & Birbaumer, 2004; Dolcos, LaBar, & Cabeza, 2004; Fichtenholtz et al., 2004; Phan, Fitzgerald, et al., 2004; Phan, Taylor, et al., 2004; Phan, Wager, Taylor, & Liberzon, 2004; Anderson et al., 2003; Phillips, Drevets, Rauch, & Lane, 2003; Adolphs, 2002; Yamasaki, LaBar, & McCarthy, 2002). In conditions of competing emotion–cognition interactions, the neural system involved in "hot" emotional (HotEmo) processing interplays with a neural system involved in "cold" executive (ColdEx) processing, which includes brain regions that are part of the so-called fronto-parietal attentional network, that underlies the ability to stay focused on task-relevant information and is important for cognitive control (Corbetta, Patel, & Shulman, 2008; Ochsner & Gross, 2005; Corbetta & Shulman, 2002; Duncan & Owen, 2000).

Dissociating Neural Responses Reflecting Detrimental Impact of versus Reduced Emotional Distraction

Although previous investigations identified the role of HotEmo brain regions in various aspects of emotion processing and emotion–cognition interactions (Dolcos et al., 2011), less is known about their involvement in the response to emotional distraction associated with the detrimental impact on behavioral performance versus those involved in minimizing the impact of such distraction on performance, especially when examining emotional distraction during lower-level perceptual tasks (but see Dolcos, Kragel, Wang, & McCarthy, 2006; Dolcos & McCarthy, 2006, for emotional distraction and cognitive control in higher-level working memory tasks). In previous studies with emotional distraction (Denkova et al., 2010; Dolcos et al., 2006; Dolcos & McCarthy, 2006), the role of brain regions whose activity was differentially sensitive to the

presence of emotional distraction was further elucidated by examining brain–behavior relationships reflected in co-variations of brain activity with task performance. These investigations showed that brain areas of the HotEmo system where activity covaried negatively with task performance were associated with responses reflecting increased distraction (Denkova et al., 2010), whereas areas of the ColdEx system where activity covaried positively with task performance or decreased distractibility were associated with responses reflecting the engagement of cognitive control mechanisms to help cope with distracting emotions (Denkova et al., 2010; Dolcos et al., 2006; Dolcos & McCarthy, 2006). Therefore, the second main goal of the present investigation was to identify the neural correlates of emotion–cognition interactions in conditions where emotional information is presented as task-irrelevant distraction during a perception task, and to distinguish between their roles in responses reflecting the detrimental impact of versus helping with emotional distraction.

This study addressed these issues by using a perceptual orientation–discrimination task that allowed for the examination of the neural mechanisms that mediate the response to task-irrelevant emotional distraction. Brain activity was recorded using event-related fMRI while healthy participants performed this task that assessed the impact of emotional charge of distraction, perceptual load, stimulus duration, and their interactions on task performance.

On the basis of the two opposing views of how selective attention and emotion processing interact with each other, we made the following conditional predictions. First, regarding the behavioral effects, if the traditional view was correct, we predicted that automatic emotion processing would occur similarly, regardless of the amount of processing demands (high vs. low) required by the main task. On the other hand, if the nontraditional view was correct, we predicted that emotion processing would be modulated by the availability of processing resources—i.e., as processing demands of the main task increased, processing of task-irrelevant distraction (whether neutral or emotional) would decrease. However, if both views were correct, processing of emotional distraction would be both automatic and modulated by attention (i.e., behavioral data would show an effect of emotion regardless of the processing demand of the main task, but the effect of emotion would be larger when demand was low and more resources were available to process the task-irrelevant emotion). Second, regarding the neural correlates of these effects, if the traditional view was correct we predicted that processing of emotional distraction would be associated with activity in affective brain regions, and this activity would be present regardless of the processing demand of the main task. If the nontraditional view was correct, we predicted that processing of emotional distraction would be associated with greater activity in affective brain regions when processing demands of the main task were low. However, if both views were correct, we predicted that, although overall

processing of emotional distraction would be associated with similar brain activity regardless of the processing demands, certain affective regions would show an increase in activity when the processing demands of the main task was low.

Finally, we also predicted a differential link with behavioral performance between regions associated with a detrimental impact of emotional distraction versus reducing the impact of such distraction. Specifically, increased activity in regions of the HotEmo system linked to impaired performance would be associated with a negative impact of emotional distraction (Denkova et al., 2010), whereas increased activity in regions of the ColdEx system linked to enhanced performance would reflect the engagement of defensive mechanisms to help reduce the impact of emotional distraction (Dolcos et al., 2006; Dolcos & McCarthy, 2006).

METHODS

Participants

Eighteen (seven men) healthy right-handed young adults (19–33 years; average age = 23.44 years; SD = 4.13 years) recruited from the University of Alberta and Edmonton City area participated in the study. Participants signed an informed consent before participating and were reimbursed for their participation. The experimental protocol was approved for ethical treatment of human participants by the health research ethics board at the University of Alberta.

Task and Stimuli

Participants performed a perceptual orientation-discrimination task with distraction, in which they made decisions on the orientation of vertical and horizontal pictures with varying degrees of emotional content (Figure 1). This task allowed for the assessment of the impact of processing demand, emotional charge of distraction, and their interactions on the ability to make responses concerning the orientation (vertical vs. horizontal) of the rectangular pictures. Processing demand was manipulated by varying the ratio of the horizontal versus vertical sides of the rectangles, which influenced the difficulty in deciding whether the pictures were clearly rectangles (with vertical or horizontal orientation) or closer to squares (with uncertain orientation). There were 280 rectangular pictures (50% horizontal and 50% vertical). The vertical to horizontal (V/H) ratios were varied using increments/decrements of 0.006 around 1 (perfect square); the size of the starting square was 280 × 280 pixels. This resulted in 60 different rectangles with vertical to horizontal ratios ranging from 0.801 to 1.249, with a 30 horizontal and 30 vertical shapes. Among these, the 15 that were closest to a square (horizontal ratios, 0.905–0.993; vertical ratios, 1.007–1.113)
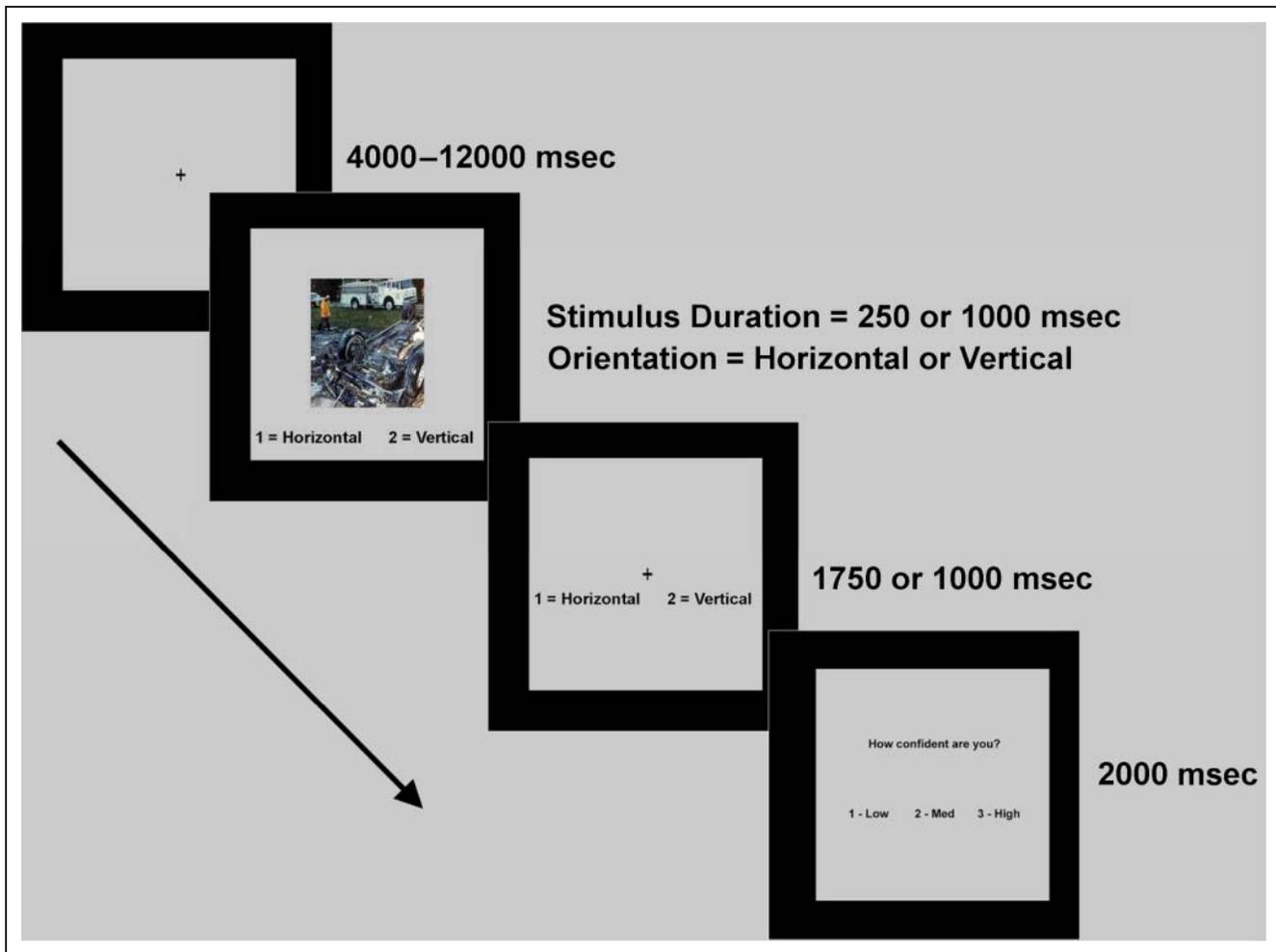
Figure 1. Diagram of the perception task showing the event order for one trial. Trial type was defined by the type of rectangular picture (HiEmo, LowEmo, Neu, AbsNeu, Scrambled), the duration that the stimulus was presented (1000, 250 msec), and the perceptual load required to successfully perform the discrimination task (low, high). Participants were instructed to determine the orientation of the rectangular picture (1, horizontal; 2, vertical) and to maintain focus on the task. Participants then followed the orientation response with a confidence rating for their response. HiEmo = High Emotional; LoEmo = Low Emotional; Neu = Neutral; AbsNeu = Absolute Neutral.

were classified as more difficult (high perceptual load), and the remaining 15 that were clearly rectangular (horizontal ratios, 0.801–0.898; vertical ratios, 1.121–1.249) were classified as less difficult (low perceptual load). Analyses of pilot data and the present results showed that this manipulation worked, as our results are comparable with those reported by studies supporting the competing view, where the emotion response was attenuated or eliminated under conditions of high attentional load (Pessoa et al., 2005). In addition, task demands were also manipulated by varying the presentation time of the stimuli (short = 250 msec vs. long = 1000 msec), which also influenced the difficulty of making the orientation decisions in the presence of concomitantly presented competing emotional information.

Distraction level was manipulated by varying the emotional content of the rectangular pictures and involved three main categories of pictures: emotionally negative (40%), emotionally neutral (40%), and scrambled (20%). Negative pictures were selected to stay consistent with previous

research examining the automaticity of emotion (Pessoa et al., 2005; Pessoa, McKenna, et al., 2002; Vuilleumier et al., 2001). The emotional and neutral pictures were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008), based on their normative scores for arousal and valence, and were supplemented with in-house pictures used in previous studies (Dolcos & McCarthy, 2006; Yamasaki et al., 2002). Next, the normative arousal and valence scores (measured on a 9-point Likert scale) were combined to create a composite score that reflects the overall emotional charge of each picture, using the following formula: 9 − valence score + arousal score. To investigate possible finer emotion-related dissociations, in addition to the basic separation between emotional and neutral categories based on their composite scores, both picture types were further divided into two within-category subgroups, using a median split separation. This resulted in four picture categories according to their emotional content (i.e., high emotional [HiEmo], low

emotional [LoEmo], neutral [Neu], and absolute neutral [AbsNeu]), which allowed for finer comparisons of the emotion effects by contrasting the most dissimilar conditions (i.e., HiEmo vs. least emotional/AbsNeu). The mean arousal, valence, and composite scores, respectively, were as follows: 6.4/2.2/13.2, for HiEmo pictures; 5.4/3.3/11.1, for LoEmo pictures; 3.7/5.0/7.7 for Neu pictures; and 3.0/5.1/6.9 for AbsNeu pictures. Pairwise comparisons found each of the emotional charge groups to be statistically significant from the others. Finally, the scrambled pictures were digitally scrambled versions of randomly selected emotional and neutral pictures (half resulting from emotional and half from neutral pictures). The scrambled pictures served as no-distraction controls that had the same average spatial frequency and luminance as the emotional and neutral meaningful pictures. All pictures were presented in color. At the end of the study, participants also rated the emotional charge of emotional and neutral pictures, using a (9-point Likert scale: 1 = *lowest*, 9 = *highest*). Participants were instructed to rate as lowest in emotional charge, those pictures that conveyed little to no emotional information and resulted in the participants' feeling completely relaxed or calm, neutral, and/or dispassionate. On the other hand, participants were instructed to rate as highest in emotional charge those pictures that had high emotional content and made them feel stimulated, excited, emotionally negative, and/or passionate (see Supplemental Information for picture rating task and results).

Experimental Procedures

The 280 trials were divided into seven runs of 40 trials (8 HiEmo, 8 LoEmo, 8 Neu, 8 AbsNeu, and 8 scrambled). Two different run orders were randomly assigned to the 18 participants to control for order effects. To avoid induction of mood states, the trials within each block were pseudorandomized so that no more than two trials of the same valence type were consecutively presented. As illustrated in Figure 1, each trial started with the presentation of a rectangular picture for 250 or 1000 msec and was followed by a fixation screen for 1750 or 1000 msec, respectively. The participants' task was to indicate the orientation of the rectangular picture (i.e., vertical or horizontal) by pressing a button. Participants were instructed to respond as quickly and as accurately as possible during the 2-sec time window, beginning with the onset of the rectangular pictures. Immediately following this interval, a confidence screen was presented for 2 sec, during which participants rated the confidence of their orientation decision on a 3-point Likert scale (1 = *lowest*, 3 = *highest*). Confidence ratings were not considered in further analysis as performance was near ceiling for the low perceptual load condition. Each trial lasted 4 sec [stimulus (2 sec) plus confidence rating (2 sec)] and was followed by a jittered fixation interval, drawn from an exponential distribution with a median of 6 sec and a range

from 4 to 12 sec. Thus, the total trial length ranged from 8 to 16 sec.

Imaging Protocol

MR scanning was conducted on a 1.5-T Siemens Sonata scanner. After the sagittal localizer and the 3-D magnetization prepared rapid acquisition gradient-echo anatomical series (field of view = 256 × 256 mm, repetition time [TR] = 1600 msec, echo time = 3.82 msec, number of slices = 112, voxel size = 1 mm^3), series of functional volumes allowing for full-brain coverage were acquired axially, using an echoplanar sequence (field of view = 256 × 256 mm, TR = 2000 msec, echo time = 40 msec, number of slices = 28, voxel size = 4 × 4 × 4 mm, flip angle = 90°).

Behavioral Data Analysis

Shape detection performance was measured as RT to making orientation discrimination decisions (vertical vs. horizontal) to the rectangular pictures. Repeated-measures ANOVAs on RT and accuracy data were employed to assess the impact of emotional charge of distraction, perceptual load, stimulus duration, and their interactions on performance in the shape detection task. To compare the impact of rough versus finer assessments of the emotional content, these analyses were performed on both the more comprehensive emotional categories (all emotional [All-Emo] vs. all neutral [All-Neu]) and on the most dissimilar emotional categories (HiEmo vs. AbsNeu). These analyses were performed on data from all 18 participants. Pairwise comparisons were Bonferroni-corrected.

fMRI Data Analysis

Imaging data analyses were performed on 18 participants, using SPM in conjunction with in-house custom Matlab scripts. Statistical analyses were preceded by the following preprocessing steps: quality assurance, TR alignment, motion correction, coregistration, normalization, and smoothing (8 mm^3 kernel). For individual analyses, task-related activity was identified by convolving a vector of the onset times of the stimuli with a synthetic hemodynamic response and its temporal derivative. The general linear model, as implemented in SPM2, was used to model the effects of interests and other confounding effects (e.g., session effects and magnetic field drift). Group analyses were conducted using random-effects models to assess the effect of distractor content, perceptual load, and stimulus duration on emotion processing. Analyses focused on brain regions associated with both basic (e.g., AMY) and higher-level emotion processing (e.g., pFC).

The main goals of the present investigation were to investigate the traditional and nontraditional views concerning the interaction between emotion and selective

attention, and to distinguish between the neural correlates of the response to the detrimental impact versus reduction of emotional distraction, based on manipulating both the emotional charge of distracting information and the demands of the main cognitive task. To accomplish these goals, activity in brain regions specifically sensitive to the presence of emotional distraction, in conditions of manipulating perceptual load, stimulus duration, and their interactions on performance in the perceptual discrimination task was first investigated. Then, activity in these regions was tested for covariations with RT data to identify responses reflecting the detrimental impact of emotional distraction versus the engagement of defensive mechanisms to help cope with distracting emotions. Increased activity to emotional distraction in emotion processing regions, coupled with positive covariations with RT (slower responses), would be indicative of a detrimental impact of emotional distraction, possibly reflecting bottom–up effects. On the other hand, negative covariations of activity in brain regions with RT (speeded responses), in response to emotional distraction, would probably reflect the engagement of top–down mechanisms, to cope with distraction. These analyses are described in detail below.

The Debate: The Traditional versus Competing Views of Emotion and Attention

To investigate the traditional and nontraditional views of emotion and selective attention interactions when considering both emotional charge and attentional demand, we first assessed the effect of manipulating the degree of emotional charge on activation in emotion processing regions. To assess emotional distraction for a more comprehensive assessment, a t map contrasting All-Emo versus All-Neu items was computed. To assess emotional distraction for the finer assessment, a t map was computed that contrasted only HiEmo versus AbsNeu items. Next, overlapping and nonoverlapping brain regions were identified between the two assessments.

To examine brain regions susceptible to emotion processing that were modulated by manipulations of perceptual load (Load) or stimulus duration (Dur), we employed subtraction analyses. First, to assess emotional distraction for low and high Load, and short and long Dur separately, t maps contrasting HiEmo and AbsNeu pictures were computed for when the task was performed under low load (Lo-Load), high load (Hi-Load), short Dur, and long Dur; these identified voxels where HiEmo pictures produced greater activity than AbsNeu pictures for each condition. Then, to identify areas of brain activity where the amount of emotional distraction was affected by Load, the individual t map for emotional distraction when Load was low or high was subtracted from the individual t map for emotional distraction when Load was high or low, [((HiEmo Hi-Load > AbsNeu Hi-Load) − (HiEmo Lo-Load > AbsNeu Lo-Load)) ∩ (HiEmo Hi-Load > AbsNeu

Hi-Load)] and [((HiEmo Lo-Load > AbsNeu Lo-Load) − (HiEmo Hi-Load > AbsNeu Hi-Load)) ∩ (HiEmo Lo-Load > AbsNeu Lo-Load)].

To identify areas of brain activity that were more susceptible to emotional modulation when Dur was short or long, the individual t map for emotional distraction when Dur was long or short was subtracted from the individual t map for emotional distraction when Dur was short or long and, [((HiEmo Short Dur > AbsNeu Short Dur) − (HiEmo Long Dur > AbsNeu Long Dur)) ∩ (HiEmo Short Dur > AbsNeu Short Dur)] and [((HiEmo Long Dur > AbsNeu Long Dur) − (HiEmo Short Dur > AbsNeu Short Dur)) ∩ (HiEmo Long Dur > AbsNeu Long Dur)].

Dissociating Neural Responses Reflecting Detrimental Impact of versus Reduced Emotional Distraction

To identify areas of brain activity reflecting the detrimental impact of versus reduced emotional distraction, we performed brain–behavior correlations between activity in regions showing the particular effects corresponding to the significant behavioral results (i.e., the main effect of Emotion and the Emotional Content × Stimulus Duration interaction) and RT data. Based on previous investigations, we expected that increased activity in regions of the HotEmo system linked to impaired performance would be associated with a detrimental impact of emotional distraction (Denkova et al., 2010), whereas increased activity in regions of the ColdEx system linked to enhanced performance would reflect the engagement of defensive mechanisms to help reduce the impact of emotional distraction (Dolcos et al., 2006; Dolcos & McCarthy, 2006).

To identify main effects in more comprehensive comparisons (e.g., All-Emo vs. All-Neu), an intensity threshold of $p < .001$, uncorrected, was used, for finer assessments of main effects (e.g., HiEmo vs. AbsNeu), a threshold of $p < .005$, uncorrected, was used, and for analyses assessing interactions (e.g., Emotion × Perceptual Load), a threshold of $p < .05$ was employed. It should be noted that for all fMRI analyses the results of the direct contrasts were reported only if they survived additional independent masking procedures; hence, the activations in the resulting conjunction maps survived multiple criteria. For example, although for an interaction (e.g., Emotion × Stimulus Duration) an independent threshold of $p < .05$ was used, the corresponding statistical map was inclusively masked by the statistical map identifying a main effect of emotion on the long-duration condition that survived an independent threshold of $p < .005$. Hence, the joint probability of the resulting conjunction map was of $p < .00025$, which is the product of their independent probabilities (0.05 × 0.005; Fisher, 1950). Similarly, for correlation analyses involving double conjunctions, the joint threshold was also of $p < .00025$, resulting from the multiplication of the threshold for the correlation t map ($p < .05$) with that of the main effect map used to inclusively mask it with ($p < .005$). Details about the joint thresholds are provided in

the legend of each figure and table. An extent threshold of five contiguous voxels was used in all analyses.

RESULTS

Behavioral Results

Reconciling the Debate: Emotion Effects Are Both Automatic and Modulated by Manipulations of Attention

Discrimination performance. When the distractors were analyzed as broad valence categories without consideration of emotional charge (i.e., All-Emo vs. All-Neu vs. Scrambled), as has been more commonly done in the existing literature, emotional content was not found to interact with task manipulations of attention (see Table 1 for a summary of mean RT and accuracy data). A main effect of Emotion and Load were found such that All-Emo distractors took longer to respond to compared with All-Neu distractors, and Hi-Load stimuli took longer to respond to compared with Lo-Load stimuli. These results confirm that emotional distractors were diverting resources from the main task and that rectangles with ratios closer to a square were harder to discriminate than those that were clearly rectangle. Importantly, this comprehensive assessment yielded no interaction effects between Emotion and Attentional Demands (see Supplemental Information section for statistical details). These findings are consistent with the traditional view regarding emotion processing, as an impairing effects of emotional distraction was found regardless of the processing demands necessary to perform the main task.

Table 1. Average RT (msec) and Accuracy (%) as a Function of Perceptual Load and Stimulus Duration for All-Emo, All-Neu, and Scrambled Distractor Trials

| | Perceptual Load | | | |
| | Low Load Stimulus Duration | | High Load Stimulus Duration | |
Distractor Type	250 msec	1000 msec	250 msec	1000 msec
All-Emo				
RT	767.99	770.44	888.84	912.10
Accuracy (%)	95.00	91.40	70.90	70.00
All-Neu				
RT	730.83	703.62	847.06	839.99
Accuracy (%)	94.60	94.80	71.50	71.40
Scrambled				
RT	696.47	702.06	794.05	840.94
Accuracy (%)	97.70	93.90	82.30	66.50

All-Emo = All Emotional distractors; All-Neu = All Neutral distractors. *n* = 18.

Further investigation of behavioral data revealed that the emotional content of the distractors interacted with manipulations of processing demands only when a finer assessment of emotional charge was considered. To test the effects of emotional charge, a three-way repeated-measures ANOVA on RT data was performed using only the most dissimilar emotional conditions (i.e., HiEmo vs. AbsNeu) and levels of Load and Duration. This finer assessment revealed a marginally significant Emotion × Duration interaction [$F(1, 17) = 4.14, p = .058, \eta^2 = 0.2$], main effects of Emotion (HiEmo > AbsNeu, $F(1, 17) = 11.35, p = .004, \eta^2 = 0.4$) and Load (Hi-load > Lo-load, $F(1, 17) = 31.9, p < .001, \eta^2 = 0.65$), but not Duration. Post hoc analyses to elucidate this interaction revealed that it was driven by participants' longer RT for HiEmo compared with AbsNeu pictures when stimulus duration was long and Load was low, $F(1, 17) = 5.83, p = .027, \eta^2 = 0.26$ (see Figure 2). These results confirm that the difference in magnitude in the emotional charge of the stimuli plays an important role in the effect of attention on emotion. Specifically, participants were more susceptible to emotional distraction when the difference in emotional content was the greatest (HiEmo vs. AbsNeu), there was more time for distraction (Long Dur), and the attentional resources were most available (Lo-Load). These findings are consistent with the competing view regarding emotion processing, and overall the behavioral results are consistent with both the traditional and the competing views.

fMRI Results

Dissociating Neural Responses Reflecting Detrimental Impact of versus Reduced Emotional Distraction

Main effect of Emotion. Overall, the behavioral results were consistent with both traditional and competing views and provide evidence that emotion processing is both automatic and modulated by manipulations of attention. This idea was also investigated in the analysis of brain imaging data. First, to assess the impact of emotional charge of distraction, we examined the neural correlates for the main effect of Emotion using both the more comprehensive assessment (All-Emo vs. All-Neu) and the finer assessment (HiEmo vs. AbsNeu). Comparison of these assessments revealed that regions susceptible to modulation by emotion (e.g., AMY, insula, and medial/inferior frontal gyri, fusiform and lateral occipital areas) underwent a larger degree of modulation when the most dissimilar emotional distractor conditions were considered (see Table 2). This was especially evident when investigating AMY activity where the strength of activation significantly decreased when using All-Emo versus All-Neu distractors compared with when using only the extremes (see Figure 3). These results emphasize the role that the overall level of emotional charge and the relative difference between emotional and neutral conditions play in producing response in both basic (AMY) and higher-level (pFC) emotion processing brain regions.

Figure 2. Emotional distraction augmented by the availability of attentional resources. Figure shows average RT data for correctly identified rectangles. Trials with HiEmo distractors resulted in longer RT than those with AbsNeu distractors in all conditions, and also revealed an interaction between emotional content and stimulus duration that was driven by Lo-Load, thus indicating that the amount of emotional distraction was augmented when more attentional resources were available for distraction. Mean and standard error for each of the eight conditions were as follows: HiEmo, Lo-Load, Short-Dur ($M = 765.37$, $SE = 48.27$); AbsNeu, Lo-Load, Short-Dur ($M = 734.46$,

$SE = 40.88$); HiEmo, Lo-Load, Long-Dur ($M = 790.26$, $SE = 46.44$); AbsNeu, Lo-Load, Long-Dur ($M = 686.85$, $SE = 35.13$); HiEmo, Hi-Load, Short-Dur ($M = 914.12$, $SE = 68.35$); AbsNeu, Hi-Load, Short-Dur ($M = 844.42$, $SE = 49.26$); HiEmo, Hi-Load, Long-Dur ($M = 922.89$, $SE = 64.2$); AbsNeu, Hi-Load, Long-Dur ($M = 827.37$, $SE = 49.97$). HiEmo = High Emotional; AbsNeu = Absolute Neutral; Lo-Load = Low Perceptual Load; Hi-Load = High Perceptual Load; Dur = Duration. *Interaction significant at $p < .05$, two-tailed.
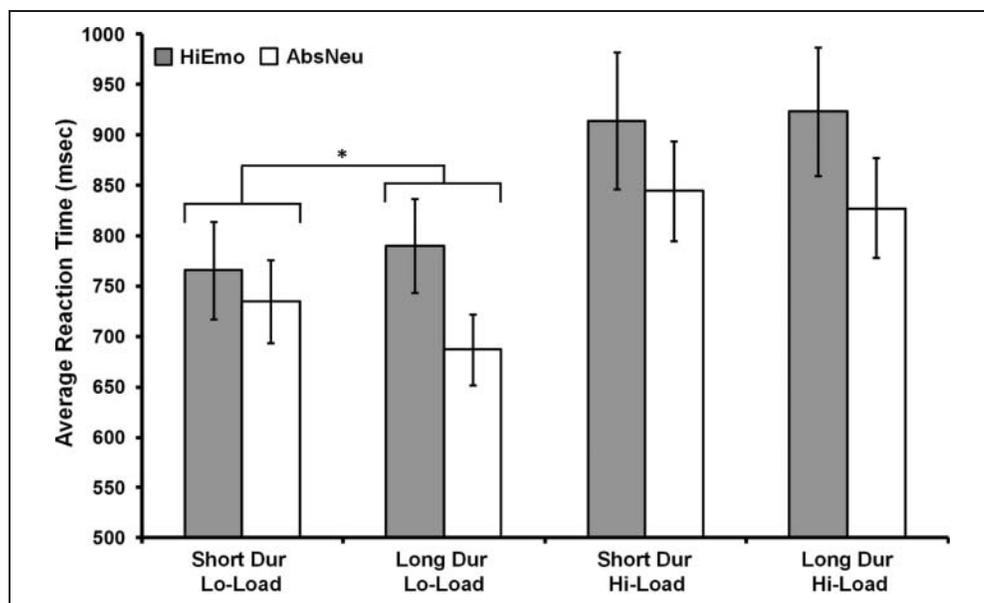
Importantly, these analyses also identified the neural correlates of responses reflecting the detrimental impact of emotional distraction, which parallels the main effect of Emotion observed behaviorally, supporting the traditional view. Given that overall emotional stimuli were associated with longer RT, increased activity in these regions may reflect longer processing time needed to make the orientation responses to these stimuli. Consistent with this idea, correlation analyses identified a significant positive co-variation between activity in the dorsomedial pFC (dmPFC; BA 8/BA 9) and the RT ($r = 0.52$, $p = .03$; peak voxel Talairach coordinates: $x = -5$, $y = 48$, $z = 34$). This finding suggests that activity in this area of the dmPFC is directly related to preferentially processing emotional over neutral stimuli and the subsequent distracting effects of emotion.

Effect of processing load on emotion processing. Given the fact that there might not be a one-to-one relationship between brain activity and behavior, we investigated how the manipulation of Load affected activity in brain regions susceptible to modulation by emotion, even in the absence of significant interactions (e.g., Emotion × Load) in behavioral results. Such an analysis revealed brain regions that reflect enhanced processing of emotion (HiEmo > AbsNeu) when processing Load was low compared with high (Lo Load > Hi Load; see Figure 4), and included the ventrolateral pFC (vlPFC), mPFC, lateral occipital cortex (LOC), and subcortical areas (i.e., ventral striatum) (see Table 3). Thus, while the behavioral data were not sensitive enough to detect changes in emotion processing as a function of Load, such changes were

identified in the brain imaging data, as some areas susceptible to emotional modulation were more engaged when the processing demands of the main task were low, hence more resources were available for distraction. This finding provides support for the nontraditional, competing, view of emotion processing.

Effect of stimulus duration on emotion processing. To further investigate the areas linked to the impairment of performance under manipulation of processing resources, the brain regions linked to modulation of emotion processing by increases or decreases of stimulus duration were then investigated (Emotion × Duration interaction). As expected, this analysis identified a number of brain regions differentially susceptible to emotional modulation for longer versus shorter processing times (see Table 4). While certain emotion processing regions showed increases in emotion processing in response to both longer and shorter duration times (e.g., dmPFC, medial occipital cortex), other emotion processing regions (i.e., the dorsal ACC [dACC], vlPFC) were more susceptible to emotion under longer stimulus durations. As the pattern of activity in these latter regions paralleled the behavioral pattern, we further investigated whether their engagement was linked to a detrimental effect of emotional distraction or to reduced emotional distraction by covarying activity in these regions with RT data.

These analyses identified a positive covariation between activity in the right vlPFC (BA 45) and RT ($r = 0.65$, $p = .004$; peak voxel Talairach coordinates: $x = 51$, $y = 24$, $z = 7$). While this correlation was primarily driven by stimulus duration (i.e., no significant relationship was present

Table 2. Heightened Emotional Response to Increased Emotional Charge

Brain Regions		BA	Talairach Coordinates			T
			x	y	z	HiEmo > AbsNeu/All-Emo > All-Neu
Overlapping areas of activation between (HiEmo > AbsNeu) and (All-Emo > All-Neu)						
mPFC	L superior/medial frontal	8	−9	43	44	5.08/2.20*
		6	−5	19	56	4.83/4.57
dlPFC	L middle frontal gyrus	9/46	−49	31	21	6.44/4.23
	R middle frontal gyrus	9	51	18	28	7.69/4.32
vlPFC	L insula/inferior frontal	13/45	−45	24	9	6.75/4.46
	L inferior frontal gyrus	47	−27	26	−12	6.28/2.51*
	R inferior frontal gyrus	47	21	26	−7	7.78/5.87
Cingulate	L cingulate gyrus	24	−1	14	31	5.86/3.85
	R cingulate gyrus	24	2	3	30	4.24/2.67**
	L posterior cingulate gyrus	31	−5	−53	24	5.46/2.25*
LOC	L inferior temporal gyrus	19	−49	73	0	12.30/8.60
	R inferior occipital gyrus	19	40	−76	−6	7.76/5.12
	L fusiform gyrus	20	−38	−37	−18	9.53/6.95
		37	−38	−56	−13	6.41/5.00
	R middle temporal gyrus	39	54	−59	14	7.54/4.22
MOC	L lingual gyrus	17	−12	−95	−5	6.3/4.03
	L cuneus	18	−24	−91	−1	4.34/3.09***
	R cuneus	18	17	−94	21	4.21/2.29*
	R middle occipital gyrus	18	21	−90	10	4.71/3.63***
Subcortical	L uncus	28	−23	5	−21	8.55/2.15*
	L AMY		−19	−3	−18	6.45/2.83**
	R AMY		14	−4	−14	8.45/3.43***
Non-overlapping areas of activation for HiEmo > AbsNeu						
Subcortical	L parahippocampal gyrus	34	−23	4	−17	6.43
	L caudate body		−9	1	11	3.42***
	L hippocampus		−30	−22	−16	5.24
	R putamen		21	14	−8	5.00
	R midbrain		10	−23	−9	4.70

Overlapping and nonoverlapping activity between comprehensive (All-Emo vs. All-Neu) and finer assessments (HiEmo vs. AbsNeu) of emotional reactivity. Analysis shows that brain regions associated with emotional response are sensitive to the magnitude of difference in emotional charge between emotional and neutral stimuli. Overlapping activity = [(HiEmo > AbsNeu) ∩ (All-Emo > All-Neu)]. Nonoverlapping activity = [(HiEmo > AbsNeu) exclusively masked by (All-Emo > All-Neu)]. The comprehensive assessment (All-Emo vs. All-Neu) did show any areas of activation that were not present in the finer assessment (HiEmo vs. AbsNeu). dlPFC = dorso-lateral prefrontal cortex; MOC = medial occipital cortex; BA = Brodmann's area; x, y, z denote coordinates in Talairach space; HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; All-Emo = All Emotional; All-Neu = All Neutral.
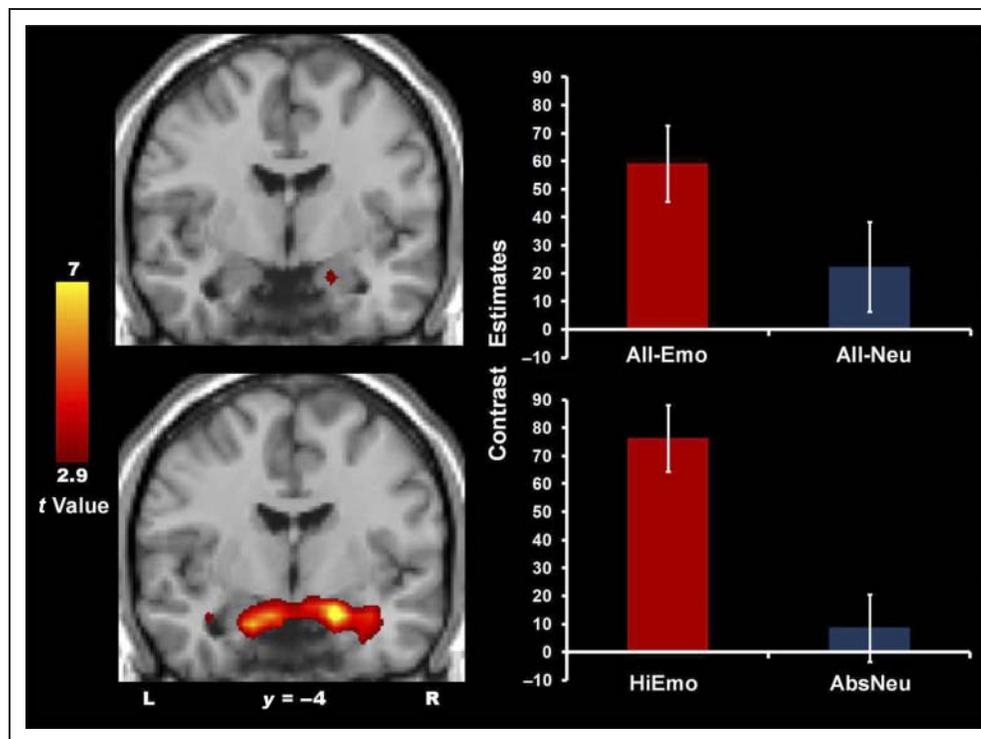
No asterisk: $p < .001$.

*$p < .05$.

**$p < .01$.

***$p < .005$.

Figure 3. AMY Sensitivity to emotional charge: Increased impact of emotional distraction when pictures with most dissimilar emotional charge are compared. The figure highlights the importance of manipulations in emotional change when investigating alterations in basic emotion processing regions. The extent of AMY activation was dependent upon the degree of difference between the emotional and neutral picture content. The top left shows unilateral AMY activation (R AMY, $t = 3.43$, $p < .005$) when All-Emo and All-Neu distractors were used for comparison, whereas the bottom left shows bilateral AMY activation surviving a higher threshold (R AMY, $t = 8.45$, $p < .001$; L AMY, $t = 6.45$, $p < .001$) when the most extreme distractors were selected for comparison (HiEmo vs. AbsNeu). The right side panels show the corresponding contrast estimates for these comparisons from the same peak voxel (Talairach coordinates: $x = 14$, $y = -4$, $z = -14$). HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; All-Emo = All Emotional; All-Neu = All Neutral.

in the same area for low [$r = 0.31$, $p = .22$] or high [$r = 0.25$, $p = .32$] Load), there was stronger activation present in this area under low, $t(17) = 2.56$, $p \leq .05$, compared with high Load, $t(17) = 1.66$, $p > .05$. This finding suggests that when more time is available for distraction, activity in the vlPFC is directly related to the distracting effects of task-irrelevant emotion on perceptual attention processing. Moreover, this region exhibited heightened sensitivity to emotional stimuli when attentional resources were not maximally engaged in a demanding task, and this was observed regardless of the effect of detrimental impact on behavioral performance (i.e., as was the case for Load).

On the other hand, a negative covariation was identified in the dACC with the RT data ($r = -0.57$, $p = .01$). To determine if, as in the behavioral data, Lo-Load trials were driving this relationship, we further examined the relationship between dACC activity and behavioral performance for Lo- and Hi-Load conditions. First areas of brain activity that corresponded with the interaction under Lo-Load were identified—activation in the dACC, LOC, and anterior insula (AI/vlPFC) was found to be strongest during such trials. Then, brain–behavior covariations between these areas of activation and the RT data for these trials were assessed. These analyses revealed that activity in the dACC (see Figure 5) and LOC was negatively correlated with the RT to HiEmo compared with AbsNeu distractors during Lo-Load and long duration trials ($r = -0.52$, $p = .03$ and $r = -0.62$, $p = .01$, respectively); importantly, this was not found for Hi-Load and long duration trials ($r = -0.29$,

$p = .24$ and $r = 0.20$, $p = .43$, respectively). These findings are consistent with the role of ACC as a region sensitive to emotion–cognition integration and conflict resolution and with the role of the LOC (specifically BA 19) in object categorization.

Taken together, these findings provide behavioral and neuroimaging evidence supporting both the traditional and nontraditional views of the interaction between emotion and selective attention and point to brain regions whose activity was linked to a detrimental effect of emotional distraction on cognitive performance and to brain regions that helped reduce the effects of such distraction on cognitive performance.

DISCUSSION

Using an experimental paradigm that manipulated both the emotional charge of distracting information and the demands of the main perceptual task, this study yielded three main findings. First, consistent with both the traditional and the competing views, we found direct evidence that emotional information can be both processed automatically and susceptible to attentional modulations. However, emotional content and attentional load were only found to interact when finer assessments of emotional charge and processing demand were considered. Second, processing of emotional distraction was associated with increased activity in brain regions that are typically part of the emotion processing network (including AMY, lateral

Figure 4. Dorsal mPFC and vlPFC areas with increased susceptibility to emotional distraction under conditions of low attentional demand. Image showing two brain regions where decreases in attentional demand of the main task resulted in increased susceptibility to emotional distraction. Specifically, areas of the mPFC and vlPFC were sensitive to emotional relative to neutral distractors only when the attentional demand necessary to perform the task was low. The left side panels show mPFC (top) and vlPFC (bottom) activations resulting from the Emotion × Load interaction where modulation by emotion only occurred under Lo-Load, and the right side panels show the corresponding contrast estimates for the peak voxels within these regions identified in the interaction analyses (Dorsal mPFC, BA 6, Talairach coordinates: $x = -2, y = 24,$

$z = 54$; L vlPFC, BA 46, Talairach coordinates: $x = -49, y = 40, z = 4$). The double conjunction map resulted from the interaction t map [(HiEmo Lo-Load − AbsNeu Lo-Load) vs. (HiEmo Hi-Load − AbsNeu Hi-Load)], which was inclusively masked with the map identifying an effect of emotion in the Lo-Load condition (HiEmo Lo-Load − AbsNeu Lo-Load). The joint probability of this double conjunction map was $p < .00025$ (resulting from $p < .05 \times p < .005$, for the interaction and mask maps, respectively). Similar patterns were also observed in the R vlPFC, L PCC, bilateral LOC, and subcortical areas (see Table 3). HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; BA = Brodmann's area; Lo-Load = Low Perceptual Load; Hi-Load = High Perceptual Load; PCC = Posterior Cingulate Cortex.
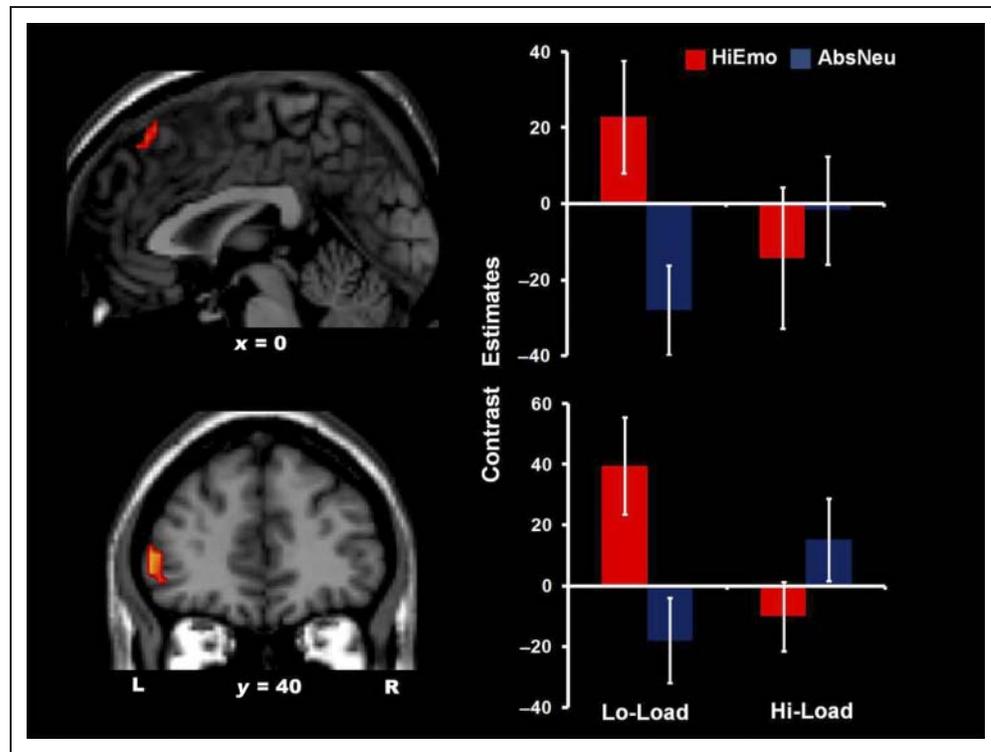
pFC, mPFC, and the occipital cortex), but activity in the dmPFC and vlPFC was also associated with a detrimental impact of emotional distraction on cognitive performance. Third, we also found that activity in the dACC and the LOC was associated with reduced emotional distraction. These findings will be discussed in turn below.

Reconciling the Debate: Emotion Effects Are Both Automatic and Modulated by Manipulations of Attention

Whether or not available attentional resources are needed for emotional information to be processed has been strongly debated in the recent emotion–cognition literature (Luo et al., 2010; Pessoa, 2010; Pourtois et al., 2010; Vuilleumier & Driver, 2007; Erthal et al., 2005; Anderson et al., 2003; Pessoa, McKenna, et al., 2002; Vuilleumier et al., 2001). Here, we provide evidence that emotional information can be both processed automatically and is susceptible to attentional modulations. Specifically, in support of the traditional view, emotional stimuli generally elicited longer RTs, suggesting that the emotional information inherent in the negative pictures was being similarly processed, regardless of manipulations of attentional demand.

On the other hand, in support of the competing view, the detrimental effect of emotional distraction on the orientation discrimination task was found to be largest when most attentional resources were available (i.e., in trials with low perceptual load and longer presentation time).

A critical aspect of our experimental design that made these findings possible was the involvement of finer assessments of the impact of emotional charge and processing demand. Regarding the emotional charge, one possible argument as to why in some cases emotion does not seem to be processed automatically is that finer assessments of emotional charge have not been taken into consideration. Indeed, although a main effect of emotional content was found in both the broad (all emotional vs. all neutral) and extreme (high emotional vs. absolute neutral) distractor analyses, the effect of emotion was stronger when isolating the extreme emotion conditions, and this effect was reflected at both behavioral and brain imaging levels (i.e., longer RT for high emotional stimuli and greater activity in the emotion processing network, respectively). These findings suggests that to a degree, the emotional information inherent in the negative pictures was probably being automatically processed regardless of manipulations of attentional demand, which is supportive of the traditional view (Vuilleumier, 2005). Regarding the manipulation of pro-

Table 3. Brain Regions Sensitive to Emotion Processing and Manipulations of Load, Despite the Absence of Behavioral Differences

Brain Regions		BA	Talairach Coordinates			T	
			x	*y*	*z*	*Interaction*	*Mask*
HiEmo > AbsNeu							
Lo-Load > Hi-Load							
dmPFC	L superior frontal gyrus	6	−2	27	54	2.78**	4.06
dlPFC	L middle frontal gyrus	9	−46	19	27	3.29***	5.05
	R middle frontal gyrus	46	51	22	25	2.81**	7.83
vlPFC	L inferior frontal gyrus	9	−57	11	33	2.86**	4.63
	L inferior frontal gyrus	45	−57	23	20	3.19***	4.41
	L inferior frontal gyrus	46	−49	40	4	3.27***	3.50***
	R inferior frontal gyrus	47	33	11	−12	3.37***	3.15***
Cingulate	L poster cingulate gyrus	23	−1	−59	17	2.05*	2.94***
LOC	L middle occipital gyrus	19	−38	−72	4	2.06*	6.50***
	L middle occipital gyrus	37	−46	−65	−6	2.09*	6.48***
	L fusiform gyrus	37	−45	−60	−11	2.04*	3.08***
	R middle temporal gyrus	22	54	−43	5	3.47***	3.89***
Subcortical	L caudate body		−9	1	19	3.60***	3.77***
	R caudate body		6	4	19	2.74**	2.99***
	L uncus	28	−23	5	−21	2.60**	7.18***
Hi-Load > Lo-Load							
Cingulate	R cingulate gyrus	24	2	−4	29	2.22*	3.73
LOC	R middle occipital gyrus	19	39	−74	9	2.48*	4.21

A number of brain regions sensitive to emotion processing were also differentially affected by load (low vs. high), even in the absence of behavioral evidence showing an effect of Load on emotional distraction. Top Interaction = [(HiEmo Lo-Load > AbsNeu Lo-Load) versus (HiEmo Hi-Load > AbsNeu Hi-Load)]. Top Mask = HiEmo Lo-Load > AbsNeu Lo-Load. Bottom interaction = [(HiEmo Hi-Load > AbsNeu Hi-Load) vs. (HiEmo Lo-Load > AbsNeu Lo-Load)]. Bottom Mask = HiEmo Hi-Load > AbsNeu Hi-Load. The joint probability of the resulting double conjunction maps was $p < .00025$ (resulting from $p < .05 \times p < .005$, for the interaction and the masking contrasts, respectively). dlPFC = dorsal lateral prefrontal cortex; BA = Brodmann's area; x, y, z denote coordinates in Talairach space; HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; Lo-Load = Low Perceptual Load; Hi-Load = High Perceptual Load.

No asterisk: $p < .001$.

*$p < .05$.

**$p < .01$.

***$p < .005$.

cessing demand, the detrimental effect of emotional distraction on the perceptual task was found to be largest not only when the emotional distraction was the most powerful but also when most attentional resources were available (i.e., in trials with low perceptual load and longer presentation time). This finding suggests that processing of emotional information was partially dependent upon the amount of attentional resources available for distraction and is thus supportive of the nontraditional view (Pessoa, 2005). The present findings also highlights the importance of task manipulations that consider both aspects that may influence performance in this task (emotional content and processing demand), as the debate over the automaticity of emotional processing is better informed here by examining various levels of the emotion and attention manipulations.

The neuroimaging data also presented evidence for both automatic and attention-regulated processing of emotional distraction. On the one hand, areas known to be involved in affective processing or to be sensitive to affective stimulation, including AMY, the lateral pFC and mPFC, insula, as well as perceptual areas (fusiform gyrus, LOC) showed greater activations to emotional compared with neutral distractors. Notably, activity in specific regions of this network was unaffected by manipulations of perceptual load and/or stimulus duration, which may reflect the automaticity of emotion processing and provide support for the traditional

view of emotion–cognition interactions (Pourtois et al., 2010; Vuilleumier, 2005; Vuilleumier et al., 2001). On the other hand, not all affective processing regions were found to have activations that were independent of manipulations of attention. Activations in specific regions (i.e., vlPFC, mPFC, LOC, and certain subcortical areas) were greater to highly emotional compared with absolute neutral trials during low perceptual load or long stimulus duration trials and were attenuated or no longer present when perceptual load was high or stimulus duration was short. These changes in responsivity to emotional stimuli across manipulations of attention demonstrate that, in some affective areas of the brain, emotional processing is modulated by the amount of available attentional resources. These findings support the nontraditional, competing, view of emotion–cognition interactions that claims that emotional stimuli compete

Table 4. Effect of Stimulus Duration on the Neural Response to Emotional Distraction

| Brain Regions		BA	Talairach Coordinates			T	
			x	y	z	Interaction	Mask
HiEmo > AbsNeu							
Long Dur > Short Dur							
dmPFC	L medial frontal gyrus	6	−2	−7	58	2.68**	3.19***
vlPFC	L inferior frontal gyrus	47	−34	29	3	2.35*	4.89
		13	−42	24	9	2.76**	5.68
	R inferior frontal gyrus	47	25	18	−12	4.65	5.73
Cingulate	L cingulate gyrus	32	−1	14	38	4.11	3.69
Parietal	R precentral gyrus	6	36	−1	30	2.24*	4.17
LOC	L inferior occipital gyrus	19	−38	−72	−3	2.88**	6.36
MOC	L cuneus	18	−20	−96	2	2.24*	3.08***
Subcortical	R thalamus		10	−16	−4	3.58***	3.24***
	R midbrain		10	−4	−10	2.11*	5.41
Short Dur > Long Dur							
dmPFC	L superior frontal gyrus	8	−13	35	54	2.60**	4.88
		8	−16	39	47	2.17*	2.93***
Insula	L insula	13	−38	−26	23	2.62**	3.17***
	R insula	13	44	−8	−7	4.23*	3.66
MPC	L precuneus	31	−24	−71	19	3.47***	4.04
LOC	R middle temporal gyrus	37	36	−60	17	2.07*	3.69
MOC	R cuneus	18	17	−78	15	3.46***	3.09***
	R middle occipital gyrus	19	28	−90	21	4.33	3.65
Subcortical	L parahippocampus gyrus	30	−20	−50	3	2.84**	3.25***
	L caudate tail		−20	−30	19	3.39***	3.04***

Unlike the pattern of activation observed with the manipulation of Load, where more regions were responsive to emotional distraction when Load was low, the manipulation of stimulus duration showed response to emotional distraction under both long and short duration times. Top Table Interaction = [(HiEmo Long Dur > AbsNeu Long Dur) vs. (HiEmo Short Dur > AbsNeu Short Dur)]. Top Table Mask = HiEmo Long Dur > AbsNeu Long Dur. Bottom Table Interaction = [(HiEmo Short Dur > AbsNeu Short Dur) vs. (HiEmo Long Dur > AbsNeu Long Dur)]. Bottom Table Mask = HiEmo Short Dur > AbsNeu Short Dur. The joint probability of the resulting double conjunction maps was of $p < .00025$ (resulting from $p < .05 \times p < .005$, for the interaction and the masking contrasts, respectively). MPC = medial parietal cortex; MOC = medial occipital cortex; BA = Brodmann's area; x, y, z denotes coordinates in Talairach space; HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; Dur = Stimulus Duration.

No asterisk: $p < .001$.

*$p < .05$.

**$p < .01$.

***$p < .005$.
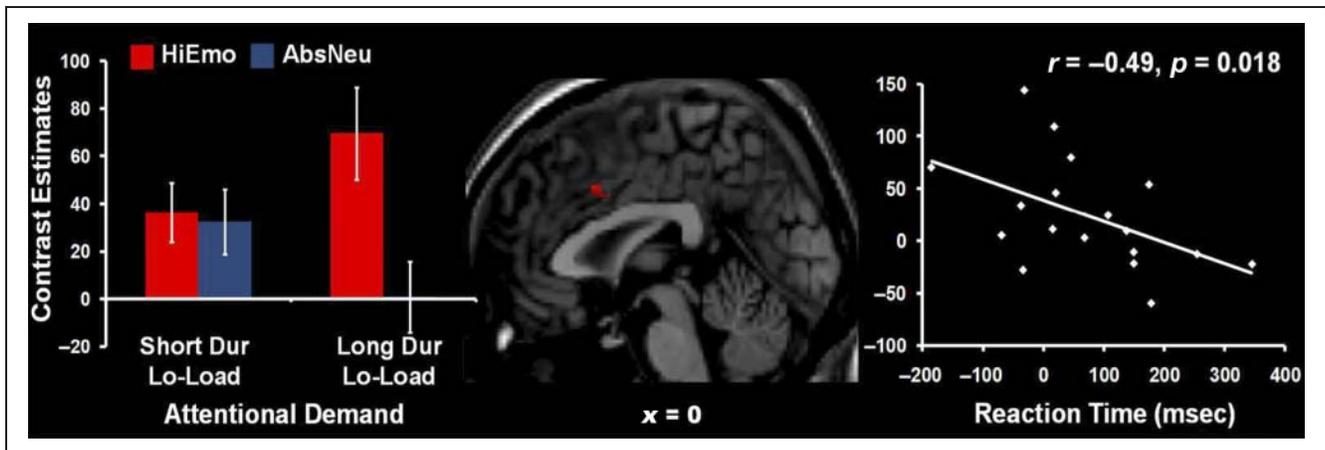
Figure 5. Dorsal ACC Activity reflected processing that helped diminish the impact of emotional distraction. Of the regions that exhibited patterns of activity paralleling the behavioral results, where emotional distraction was greatest for long versus short Dur under conditions of Lo-Load, only the dACC (BA 24) and L LOC (BA 19) negatively covaried with RT ($r = -0.49, p < .05, r = -0.62, p < .01$, respectively). The left panel shows the contrast estimates as extracted from the peak voxel in the dACC (Talairach coordinates: $x = -1, y = 10, z = 33$), where the interaction in brain imaging data that parallels the behavioral results was identified (see middle panel). The right panel shows a scatterplot illustrating the results of the correlation calculated on the contrast estimates from the peak voxel identified in the interaction analysis and the RT data. The triple conjunction map resulted from the correlation map described above, which was inclusively masked with the interaction t map identifying the interaction that parallels the behavioral findings [((HiEmo Long Dur Lo-Load) − (AbsNeu Long Dur Lo-Load)) vs. ((HiEmo Short Dur Lo-Load) − (AbsNeu Short Dur Lo-Load))] and with the map identifying an effect of emotion in the long duration and low load condition. The joint probability of this triple conjunction map was $p < .0000125$ (resulting from $p < .05 \times p < .05 \times p < .005$, for the correlation, interaction, and effect of emotion maps, respectively). Other brain regions paralleling the behavioral interaction (emotional distraction greatest for long versus short Dur under conditions of Lo-Load) were found bilaterally in the AI (BA 13, L AI, Talairach coordinates: $x = -38, y = 20, z = 9$; R AI, Talairach coordinates: $x = 29, y = 20, z = 14$), L ITG and FG (BA 37, Talairach coordinates: $x = -42, y = -65, z = -3$ and $x = -42, y = -45, z = -19$), L MOG (BA 19, Talairach coordinates: $x = -42, y = -81, z = 3$), R IFG (BA 47, Talairach coordinates: $x = 36, y = 7, z = 31$), and bilateral ACC (BA 32, L ACC, Talairach coordinates: $x = -1, y = 10, z = 38$; BA 24, R ACC, Talairach coordinates: $x = 2, y = 3, z = 33$). HiEmo = Highly Emotional; AbsNeu = Absolute Neutral; Lo-Load = Low Perceptual Load; Hi-Load = High Perceptual Load; Dur = Stimulus Duration; BA = Brodmann's area; LOC = lateral occipital cortex; ITG = inferior temporal gyrus; FG = fusiform gyrus; IFG = inferior frontal gyrus.

for processing resources with other stimuli (Pessoa, 2005; Pessoa et al., 2005; Pessoa, Kastner, & Ungerleider, 2002).

The fact that the latter activations were observed in the absence of a significant emotion–perceptual load interaction in the behavioral data point to the complexity of the interactions between the HotEmo and ColdEx systems, which does not always allow for a direct one-to-one relationship between brain and behavior. Nevertheless, these activations are valuable to consider, as differences in processing at the brain level may not always be reflected in overt behavioral measures. At any rate, the present behavioral and brain imaging findings provide direct evidence that the two views concerning basic emotion processing are not mutually exclusive and that depending on the circumstances emotional information can be processed automatically but is also susceptible to modulations linked to the availability of attentional resources.

Dissociating Neural Responses Reflecting Detrimental Impact of versus Reduced Emotional Distraction: dmPFC and vlPFC Activity Linked to a Detrimental Impact of Emotional Distraction versus dACC and LOC Activity Linked to Reduced Emotional Distraction

Among the regions showing overall increased sensitivity to the presence of emotional distraction, the dmPFC (BA 8/

BA 9) was also directly associated with the orientation discrimination performance, as expressed in the RT data. Specifically, activity in this region was positively correlated with the time needed to make the orientation discrimination decision to emotional compared with neutral distraction—as the RT to emotional relative to neutral distraction increased, activity in the dmPFC also increased. While a consistent functional role for mPFC as a whole has yet to be clarified (Etkin, Egner, & Kalisch, 2011), previous research with emotional distraction has found an increase in activation or reduction in deactivation in the mPFC (Denkova et al., 2010; Geday & Gjedde, 2009; Gjedde & Geday, 2009; Geday, Kupers, & Gjedde, 2007; Liberzon et al., 2007; Northoff et al., 2004), suggesting this area to be responsive to emotional interference. Moreover, the fact that in our study the response of the dmPFC to negative distraction was unchanged across levels of perceptual load and stimulus duration suggests that activity in this region may be linked to the ventral attentional network, which is an automatic, stimulus-driven, and bottom–up system (Fox, Corbetta, Snyder, Vincent, & Raichle, 2006; Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005; Corbetta & Shulman, 2002; Posner & Petersen, 1990). This interpretation is consistent with evidence that activity in a similar dmPFC region was specifically associated with processing of emotional arousal, rather than valence (Dolcos

et al., 2004), suggesting a role of this region in processing information with enhanced motivational relevance (Goldin, McRae, Ramel, & Gross, 2008; Holzel et al., 2007; Phan et al., 2003; Taylor, Phan, Decker, & Liberzon, 2003; Gusnard, Akbudak, Shulman, & Raichle, 2001; Simpson, Snyder, Gusnard, & Raichle, 2001; Northoff et al., 2000; Lane et al., 1998; Lane, Fink, Chau, & Dolan, 1997), which may explain longer RTs associated with the response to negative distraction.

In addition to the dmPFC, the vlPFC was also directly associated with orientation discrimination performance as measured by latency to respond. Activity in this region was positively correlated with RT to emotional compared with neutral distraction under long stimulus exposure durations compared with short durations, suggesting that increased activity in this region is associated with enhanced detrimental impact of the emotional distraction. This finding is consistent with evidence that this region is involved in reflexive orienting to motivationally relevant stimuli in the environment (Corbetta et al., 2008), and with evidence of its involvement in emotional perception, in general (Dolcos et al., 2004; Phan, Wager, Taylor, & Liberzon, 2002), and in the response to emotional distraction, in particular (Dolcos et al., 2006, 2011; Anticevic, Repovs, & Barch, 2010; Denkova et al., 2010; Dolcos & McCarthy, 2006).

This study also provided evidence concerning the neural correlates of mechanisms engaged to reduce emotional distraction. In addition to the network of brain regions consistent with the main effect of emotional distraction mentioned above, this study also identified brain regions linked to Emotion × Perceptual Load × Stimulus Duration interaction observed in the behavioral data. This analysis identified the brain areas involved when emotional distraction produced the strongest effect (i.e., activations to highly emotional-low perceptual load and long stimulus duration trials), which included the dACC, IFG, and LOC. Further analyses elucidating the contribution of these regions to the observed effect to relate their activations to the actual behavioral performance revealed that activity in both the dACC and LOC was negatively correlated with RT, which is consistent with an engagement of these regions to minimize emotional distraction.

Given the evidence concerning the role of dACC in top–down control, the present findings are not surprising. ACC is an area of cortex commonly associated with conflict monitoring (Botvinick, Cohen, & Carter, 2004), and dACC is part of the dorso-parietal attention network (Bush, Luu, & Posner, 2000), associated with executive control (Corbetta et al., 2008; Ochsner & Gross, 2005; Corbetta & Shulman, 2002; Duncan & Owen, 2000). Additionally, dACC activity is systematically found in tasks with emotional and cognitive components (Phan et al., 2002), as well as in tasks in which emotional processing is modulated by manipulations of attentional demand (Mohanty et al., 2007; Whalen, Bush, et al., 1998). Finally, ACC activity has been consistently found in tasks where, similar to this study,

goal-irrelevant emotional information is spatially contiguous with the target, such as the emotional Stroop task (Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Haas, Omura, Constable, & Canli, 2006) and the emotional flanker task (Kanske & Kotz, 2010; Whalen, Bush, et al., 1998).

In the context of the present task, due to the association with improved performance under conditions of high emotional distraction, ACC and LOC response likely reflects the enhancement of task-relevant stimulus features (vertical/horizontal orientation), to successfully cope with the presence of emotional distraction. This is consistent with evidence that LOC is an area of cortex commonly responsive to the perception and categorization of scenes and objects (Walther, Caddigan, Fei-Fei, & Beck, 2009; Grill-Spector et al., 1998, 1999; Malach et al., 1995); hence, it is reasonable to work jointly with ACC to help cope with emotional distraction when attentional resources are most susceptible to be "captured" by task-irrelevant emotional information. The idea that ACC aids in coping with emotion is further supported by research demonstrating altered ACC reactivity to emotional stimuli in individuals high in trait anxiety (Simmons et al., 2008) or with a diagnosis of post-traumatic stress disorder (Bremner et al., 2004; Shin et al., 2001), generalized anxiety disorder (Etkin, Prater, Hoeft, Menon, & Schatzberg, 2010), or major depressive disorder (Halari et al., 2009).

It should be noted that, although the present results provide valuable insight to the interaction between negative stimuli and attention, a limitation of this study is that interpretation of results is limited to negative stimuli. Only negative picture were involved to stay consistent with previous research examining the automaticity of emotion (Pessoa et al., 2005; Pessoa, McKenna, et al., 2002; Vuilleumier et al., 2001), but given the evidence concerning valence-related differences in the impact of emotion on attention (Shaw, Lien, Ruthruff, & Allen, 2011; Beall & Herbert, 2008; Schupp et al., 2004; Anderson et al., 2003), examination of the impact of positive distraction would be valuable in understanding the role that valence plays in interacting with attention under various manipulations of perceptual load. Future studies should investigate whether the effects identified here also apply to positive distraction.

Conclusions

In summary, this study provided direct evidence in support of both automatic and attention-dependent processing of task-irrelevant emotional information. As such, neither the traditional nor the nontraditional view of emotion–cognition interactions appears to fully account for the present results, which are instead consistent with both views. First, we found evidence that emotion processing occurs automatically, but is also influenced by the emotional charge of the stimuli used and by the amount of attentional resources available for processing. Second, we

found evidence that, whereas activity in the dmPFC and vlPFC was linked to enhanced impact of emotional distraction, activity in the dACC and LOC aided in reducing such distraction. Better delineation of the complex relationships between emotion and cognition not only has theoretical value in a broader context but also lends insight into understanding affective disorders, in which these relationships are dysfunctional, and possibly into understanding the mechanisms involved in the susceptibility to these clinical conditions.

Acknowledgments

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