Bottom-up and Top-down Processes in Emotion Generation: Common and Distinct Neural Mechanisms

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Bottom-up and Top-down Processes in Emotion Generation:
Common and Distinct Neural Mechanisms

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Figures: 4

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Bottom-up and Top-down Processes in Emotion Generation

ABSTRACT

Emotions are generally thought to arise through the interaction of bottom-up and top-down processes. However, prior work has not delineated their relative contributions. In a sample of 20 females, we used fMRI to examine the neural correlates of negative emotions generated by the bottom-up perception of aversive images versus the top-down interpretation of neutral images as aversive. We found that 1) both types of responses activated the amygdala, although bottom-up responses did so more strongly, 2) bottom-up responses activated systems for attending to and encoding perceptual and affective stimulus properties whereas top-down responses activated prefrontal regions that represent high-level cognitive interpretations, and 3) self-reported affect correlated with activity in the amygdala during bottom-up responding and in the medial PFC during top-down responding. These findings provide a neural foundation for emotion theories that posit multiple kinds of appraisal processes and clarify mechanisms underlying clinically relevant forms of emotion dysregulation.
How do emotions arise? Do they arise via low-level processes that provide quick, bottom-up affective analyses of stimuli? Or do they arise via high-level, top-down cognitive appraisal processes that draw upon stored knowledge? This has long been one of the most contentious issues in the field (Lazarus, 1982; Zajonc, 1984), and these opposing viewpoints have only gradually yielded to a synthetic perspective which holds that both types of processes are important for emotion generation (Scherer, Schorr, & Johnstone, 2001).

**Bottom-up and Top-down Processes in Emotion Generation**

Despite the long history of interest in this issue, direct evidence of separable bottom-up and top-down processes in emotion generation has been remarkably scarce. In part, this is because behavioral studies that have been the coin of the realm for much of the field’s history measure only the inputs to and outputs of emotion generative processes, and as a consequence, cannot specify which particular processes were involved in generating a given emotion.

Researchers in other areas have dealt with this type of problem by using neuroscience methods to clarify the mechanisms underlying processes of interest (Kosslyn, 1994). Although neuroscience methods have a similar potential in the domain of emotion, to date neuroscientists have focused primarily on the bottom-up processes involved in simple forms of affective perception, learning, and memory (LeDoux, 2000; Phelps, 2006). In so doing, they have successfully identified brain systems – such as the amygdala – involved in the learning and bottom-up triggering of emotion across species. But they have paid less attention to cognitive processes involved in top-down emotion generation (T. D. Wager et al., 2008). Although neuroimaging studies have begun to examine top-down and not only bottom-up processes, they have not been designed to distinguish their relative contributions to a given emotional response (e.g. Phelps et al., 2001; Teasdale et al., 1999).

**The Present Study**

The goal of the present study was to use functional magnetic resonance imaging (fMRI) to determine whether common or distinct neural systems are involved in generating a negative emotional response via either bottom-up or top-down processing. To achieve this goal, we
examined responses to (1) normatively aversive images (Bottom-up trials) and (2) novel trials in which participants cognitively interpreted neutral images as aversive (Top-down trials). Visual images were chosen as stimuli because of their well-characterized affective properties (Lang, Greenwald, Bradley, & Hamm, 1993). These two conditions were designed to depend primarily on either bottom-up or top-down processing, respectively, although we recognized that it is not possible to make a task condition completely process pure (Jacoby, Toth, & Yonelinas, 1993). Our aim was to capitalize on the power of functional imaging to dissociate the mechanisms underlying each type of emotion processing in a way not possible using behavioral methods alone (Kosslyn, 1994). Using this approach, we sought to test three hypotheses about the neural mechanisms involved in each type of emotion generative processing.

First, we hypothesized that both bottom-up and top-down generation might depend on regions like the amygdala, which are involved in learning about and triggering responses to emotionally salient stimuli (LeDoux, 2000; Phelps, 2006). Second, we hypothesized that each type of generation might take a different route to their common influence on affective learning systems. On one hand, if bottom-up generation entails encoding the affective value of stimulus features, then viewing aversive images should activate the amgydala in concert with posterior cortical regions implicated in attending to and encoding visual features (Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Whalen et al., 2004). On the other hand, if top-down generation relies on high-level processes that elaborate the emotional meaning of stimuli and experiences, then it should differ from its bottom-up counterpart in its dependence on prefrontal regions implicated in cognitive control (Ochsner & Gross, 2005). In particular, we expected medial prefrontal cortex (mPFC) to play a key role because of its connections with subcortical regions implicated in emotional responding and its association with attention to and reasoning about emotion (Lane & McRae, 2004; Ochsner, Knierim et al., 2004; Ongur, Ferry, & Price, 2003; T. D. Wager et al., 2008). Third, we expected that if the amygdala and mPFC are critical for generating emotion “from the bottom-up” or “from the top-down”, then activity for each region might be correlated with the magnitude of affective response only on bottom-up or on top-down
Bottom-up and Top-down Processes in Emotion Generation

trials, respectively\(^1\). Finding such condition-specific correlations would both confirm the roles that these regions play in each pathway to emotion and clarify which neural systems are most closely linked to self-reported experience.

**METHODS**

**Participants**

In compliance with the human subjects regulations of Stanford University, 20 female participants (\(M_{\text{age}} = 20.3\) years) were paid $60 for voluntary completion of this study. Only women were studied to reduce variability introduced by potential gender differences in emotional responding (T. D. Wager, Phan, Liberzon, & Taylor, 2003).

**Behavioral Paradigm**

In a session 3-4 days prior to scanning, participants received training in how to perform the task using a separate set of images matched to those used in the scanner (for procedural details see Ochsner et al, 2004). During the task, participants viewed both neutral and normatively aversive images selected from the International Affective Picture System that were balanced for valence and arousal across instruction types. There were two main types of trials. On Top-down negative trials, participants were instructed to think about the actions, persons, and outcomes depicted in neutral images (e.g. an unmade bed) in ways that made them feel negative (e.g. the couple who just slept there were killed in a car accident). On Bottom-up negative trials participants were instructed to simply view images and let themselves respond naturally\(^2\). A third Bottom-up neutral trial type provided a common baseline that differed only in instruction type from Top-down negative trials and only in stimulus type from Bottom-up negative trials. As illustrated in Figure 1, comparisons a) between Top-down negative and Bottom-up neutral trials and b) between Bottom-up-Negative and Bottom-up-Neutral trials were used to reveal the

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\(^1\) We assume that networks are crucial for each type of responding, with different regions – like the amygdala or mPFC – relatively more important “rate-limiting steps” for each one.

\(^2\) In prior work this type of instruction has resulted in bottom-up emotional responses to stimuli with relatively little deliberate engagement of top-down control processes (see, e.g. papers reviewed in Ochsner & Gross, 2008).
effects of each type of emotional processing. Twenty-seven images were shown for each of
these three trial types. In addition to these three key trial types, there were three other trial types
that focused on top-down appraisals that concerned not emotion generation, but rather the up- or
down-regulation of responses to aversive or neutral images. Contrasts involving these trial types
have been reported elsewhere (Ochsner, Ray et al., 2004).

Each trial began with an initial 2-second instruction cue. The word Increase cued
participants to increase negative emotion on Top-down trials. The word Look cued participants
to look at and respond naturally to images on Bottom-up trials. Participants followed these
instructions during the subsequent 10-second presentation of an aversive or neutral image. They
then had 4 seconds to rate the current strength of their negative affect (0 = weak, 7 = strong) on a
scale consisting of a horizontal rectangular bar that grew from left to right to provide a
continuous graded index of the subjective experience of emotion. A keypress was made when
the bar’s size indicated the strength of negative affect on the associated scale. The word RELAX
appeared during a 4-second inter-trial interval.

MRI Data Acquisition and Analysis

At 3T (GE Signa LX Horizon Echospeed scanner) twenty-five 4 mm axial slices (1mm
gap) were collected using a T2*-sensitive gradient echo spiral-in/out pulse sequence (30 ms TE,
2000 ms TR, 2 interleaves, 60° flip angle, 24 cm field of view, 64x64 data acquisition matrix).
T2-weighted scans were acquired for anatomical localization using the functional slice
prescription (2000 ms TR; 85 ms TE). Following established protocols using SPM2 (Ochsner,
Ray et al., 2004), preprocessing (slice time and motion-correction, co-registration, normalization
and reslicing to 2x2x2 mm voxels) was followed by a general linear model analysis that modeled
the instruction and rating periods as events and the photo and relaxation periods as hrf-convolved
boxcars for each participant, with group random effects analyses thresholded at p < 0.001
uncorrected, k = 50 voxels. These parameters corresponded to an overall alpha level of p < .05
corrected for multiple comparisons as calculated by the Monte Carlo simulation method
implemented in AFNI that takes into account both family-wise error and extent thresholds (e.g.
Bottom-up and Top-down Processes in Emotion Generation

Ochsner, Knierim et al, 2004). Given a priori interest in the difficult to image amygdala, the whole brain threshold was dropped to \( p = .05 \) to identify active voxels within a structural region of interest defined by the amygdala coordinates in the WFU Pickatlas. BrainVoyager was used for display and for correlational analyses relating changes in brain activity to changes in self-reported affect.

To identify the neural bases of each type of emotion generation we first contrasted activity on Bottom-up negative vs. Bottom-up neutral trials (henceforth the “Bottom-up emotion generation contrast”) and on Top-down negative vs. Bottom-up neutral trials (henceforth the “Top-down emotion generation contrast”). Common neural bases were identified using a conjunction analysis. Distinct neural bases were identified by directly comparing activity in the Bottom-up and Top-down emotion generation contrasts within a mask comprised of the regions active in both contrasts. This restricted the search for regions more active during one type of emotion generation to regions known to be active during at least one of them. For all activated regions parameter estimates were extracted and compared in planned pairwise t-tests (\( p < .05 \)) to confirm their common or distinct status.

RESULTS

Manipulation Check

To confirm that negative emotions were generated on both Bottom-up negative and Top-down negative trials, we used planned t-tests to compare self-reported affect on all trial types. These tests confirmed that relative to Bottom-up neutral (\( \bar{M} = 3.58, SE = .14 \)) trials, both Bottom-up negative (\( \bar{M} = 5.89, SE = 0.22, t(19) = 11.68, p < .001 \)) and Top-down negative (\( \bar{M} = 5.24, SE = 0.24, t(19) = 8.26, p < .001 \)) trials elicited more negative affect, with Bottom-up negative trials eliciting the most negative affect of all (\( t(19) = 4.43, p < .001 \) vs. Top-down negative). The relation between self-reported emotion and brain activity is considered below, and in the discussion.

Common Neural Bases for Bottom-up and Top-down Emotion Processing

A conjunction analysis revealed one region commonly involved in both types of emotion
Bottom-up and Top-down Processes in Emotion Generation

processing – the left amygdala (Table 1 and Figure 2A-B). This region included almost all the voxels active during Top-down negative trials and was of *a priori* interest given the amygdala’s known role in emotion. Activation timecourses extracted from this cluster’s peak voxel showed activity on both Top-down and Bottom-up negative trials (Figure 2c). Planned comparisons on extracted parameter estimates confirmed that this subregion of the amygdala showed significant (p < .05) and equivalent (p > .5) activity on Top-down and Bottom-up negative trials, whereas comparisons for non-overlapping regions in both the right and left amygdala confirmed that they were active only during Bottom-up negative trials (p < .05).

**Distinct Neural Bases for Bottom-up or Top-down Emotion Generation**

Regions distinctly involved in bottom-up emotion generation included bilateral amygdala, occipitotemporal cortex, and right parietal cortex and lateral PFC. Regions distinctly involved in top-down emotion generation included left ventral and dorsal lateral PFC, bilateral dorsal medial prefrontal and anterior cingulate cortex (in one cluster spanning Brodman Areas 8, 9 and 24), and bilateral temporal cortex and putamen (Table 1, Figure 3).

**Relationship Between Brain Activity and Magnitude of Affective Response**

If the amygdala and mPFC are the key structures for bottom-up and top-down emotion generation, respectively, then their activity should predict the magnitude of affective response, indexed here by self-reported negative affect. To address this hypothesis, we used BrainVoyager to search for voxels whose activity was correlated with increases in negative affect on each negative trial type in comparison to Bottom-up Neutral trials. The mask was created at a more liberal threshold of p = .05 both because regions correlated with behavior often are not identical to those showing main effects and to avoid false negative findings. For each region, we then determined if it was correlated with affect more strongly (p < .05) for one type of emotion generation as compared to the other using the method for comparing dependent correlations. Results showed that self-reported negative affect was more strongly correlated with activity in the bilateral dorsal/sublenticular extended amygdala or in the dorsal mPFC during bottom-up or top-down emotional responding, respectively (Table 2, Figure 4).
Bottom-up and Top-down Processes in Emotion Generation

DISCUSSION

Contemporary emotion theory holds that bottom-up and top-down processes are important to emotion generation. However, behavioral research has failed to differentiate their contributions and the majority of neuroscience work has addressed only bottom-up processing. The goal of this study was to probe bottom-up and top-down processes in emotion generation using fMRI measures that could help disambiguate the common and unique mechanisms associated with each one. To achieve this goal, we compared brain activation during the simple bottom-up perception of aversive images versus the top-down interpretation of otherwise neutral images as aversive. Three key findings were obtained.

Evidence for Common and Distinct Mechanisms

First, we found that the left amygdala showed overlapping activity during both types of emotional processing. This region has been implicated in affective learning (LeDoux, 2000), which suggests that bottom-up and top-down emotional responses may share a dependence on systems that mediate learning about the affective properties of stimuli. The fact that bottom-up responses drove both amygdalae but top-down responses modulated only the left amygdala fits with prior studies (Glascher & Adolphs, 2003; Ochsner & Gross, 2008; Phelps et al., 2001) suggesting that the left amygdala may be more susceptible to influence by top-down inputs during emotion and anxiety.

Second, we found that distinct cortical networks were involved in each type of emotion generation. On one hand, bottom-up emotion generation activated the amygdala and occipital cortex, which have been implicated in detecting affectively arousing stimuli and modulating their encoding into memory (LeDoux, 2000; Phelps, 2006; Sabatinelli et al., 2005), as well right prefrontal and parietal regions implicated in attentional vigilance and individual differences in negative affective style (Davidson, 2000; Posner & Petersen, 1990). On the other hand, top-down emotion generation activated left prefrontal, cingulate and temporal regions implicated in working memory and the retrieval of information from semantic memory (Badre & Wagner, 2007), as well as the left amygdala and a dorsal mPFC region involved in making attributions.
Bottom-up and Top-down Processes in Emotion Generation

about mental – and especially emotional – states (Lane & McRae, 2004; Ochsner, Knierim et al., 2004). Working together, these systems may support cognitive appraisals that generate emotions from the top-down.

Third, we found that activity in the dorsal portions of amygdala tracked with the magnitude of self-reported experience only during bottom-up responding, whereas activity in dorsal mPFC tracked with self-reported experience only during top-down responding. Although prior studies have shown experience-activity correlations in these regions (Abercrombie et al., 1998; Ochsner, Ray et al., 2004; Phan et al., 2003), they were not designed to determine whether bottom-up or top-down processes were responsible. In humans, the dorsal amygdala has been implicated in perceiving and orienting to arousing and potentially anxiety-provoking stimuli (Davis et al, 1999; Liberzon et al, 2003; Whalen, 2004), functions that may be critical for the stimulus-triggered emotional responses studied here on bottom-up negative trials. By contrast, the dorsal mPFC correlation during top-down responding highlights the role of this region as an integrator of cognitive and affective inputs that can exert control over autonomic centers and modulate emotional experience as a function of the cognitive meaning ascribed to a stimulus in a given task (Lane & McRae, 2004; Ochsner, Knierim et al., 2004). The fact that self-reported emotion correlated with activity in discrete regions needn’t mean those are the only regions involved in affective experience, however, or that those regions represent the contents of awareness. Indeed, in the context of the networks identified in the group contrasts, these correlations likely reflect the specific “rate limiting” processes within the larger network that are most strongly related to individual variability in experience.

One potential caveat concerns the finding that self-reports of negative affect were slightly greater for Bottom-up than for Top-down negative trials, which raises the possibility that differences in brain activity reflect only differences in strength of affect. If this were true, then we would have expected to find greater activity for Bottom-up than Top-down negative trials, but not the reverse - and most critically – that the same regions would correlate with increases in self-reported emotion for both trial types, with the correlation strongest for bottom-up negative
trials. Neither was found: as described above, on Top-down negative trials activity was greater in many theoretically predicted regions and was correlated with affect in a region different than that found for Bottom-up negative trials (Figures 3 and 4). Thus, we take the imaging data to reflect the generation of slightly different quantities of negative emotion by qualitatively different low-level perceptual as opposed to high-level cognitive processes.

Another caveat concerns our inclusion of only female participants, which raises the question as to whether the present results generalize to men. Studies of cognitive emotion regulation have reported either no gender differences (T. D. Wager, Davidson et al, 2008) or that women show greater prefrontal and lesser amygdala modulation (McRae et al, 2008). These data suggest that the present cognitive emotion generation effects likely generalize to men, although the genders may differ in the extent to which they recruit top-down processes. This will be important to address in future research.

Implications for Emotion Theory and Research

Taken together, the present findings have three kinds of implications for emotion theory and research. The first concerns the question that motivated this paper: how do emotions arise? The present data provide strong evidence for separate, but related bottom-up and top-down mechanisms that depend on links between the amygdala and either perceptual representations that are accessed from the bottom-up or high-level cognitive representations of stimulus meaning that are accessed from the top-down. Intriguingly, both types of emotion generation activated prefrontal cortex. Whereas left PFC activity during top-down generation is consistent with increased semantic processing, right PFC activity during bottom-up generation may relate to attention shifting. For example, the mere perception of an emotional stimulus could trigger a parietal lobe mediated attentional shift to its affective attributes, which in turn recruits prefrontal mechanisms to further direct attention to the stimulus, possibly enhancing occipital and amygdala activity as a result (cf. Wright et al, 2008). This highlights that top-down and bottom-up processes may be co-active in many circumstances, and that any task may only partially disentangle them. That being said, the present method provides a starting point for
Bottom-up and Top-down Processes in Emotion Generation

distinguishing the contributions to experience of bottom-up and top-down processes, which could help clarify the meaning of commonly observed prefrontal activity in studies of emotion (Wager, Barrett et al, 2008) and other mixed findings from prior research. For example, it has been reported that amygdala lesions do not impact retrospective reports of global mood (Anderson & Phelps, 2002) even though they do disrupt preferences for, and judgments of arousal elicited by, visual stimuli (Ralph Adolphs, Russell, & Tranel, 1999; R. Adolphs & Tranel, 1999). One possibility is that global reports of mood given at the end of a day depend upon the retrieval of stored knowledge and top-down mPFC mechanisms to a greater extent than they depend on more transient stimulus-driven emotional responses that may be more associated with the amygdala (Barrett et al, 2007).

The second implication concerns the question of how best to study emotion mechanisms. One method would be to follow the logic of neuroscience studies that use stimuli with intrinsic pleasant and unpleasant properties (like shock), or that have social signal value but do not elicit strong emotional responses (like faces) in learning, memory and perception paradigms that depend strongly on bottom-up processes we share with non-human primates and rodents. In so doing, this work implicitly treats emotions as if they are properties of stimuli, like shape, size or color, rather than products of contextually-sensitive appraisals that can involve top-down processes humans may not share with lower animals. The present imaging study joins prior behavioral work to suggest that a bottom-up account of emotion only tells half of the story: Emotions may be generated by top-down processes as well, and for any given response, it is important to understand the type or combination of processes from which it arose. An important goal for future research will be to continue to differentiate the contributions of bottom-up and top-down processes to emotion, given that both likely contribute to emotion in many, if not all, situations.

The third implication concerns the relationship between emotion generation and emotion regulation. The finding that top-down (i.e. cognitively constructed) negative emotion involves prefrontal-amygdala interactions converges with research showing similar neural dynamics
Bottom-up and Top-down Processes in Emotion Generation

supporting cognitive reappraisal (reviewed in Ochsner & Gross, 2005, 2008) and the effects of
expectancies on pain and emotion (Tor D. Wager, 2005). This similarity suggests that a core
neural dynamic may underlie the use of high-level cognition to initiate an emotional response –
as shown here – or to modify or stop an emotional response, as shown in prior work. This
implies that the line separating emotion generation and regulation cannot be defined in simple
anatomical terms. That is, there may not be brain centers uniquely dedicated to emotion
generation or regulation, *per se*. Instead, various brain systems may perform computations
involved in both, depending on the behavioral context. Thus, which term we use may depend
more on our functional analysis of the situation than on the neural systems involved.

**Implications for Developmental, Social and Clinical Psychology**

The view that emotions may arise via different combinations of bottom-up or top-down
processes has implications for at least three areas of psychological research. The first is
developmental research, which has shown prefrontal maturation through the teen years that often
is taken to reflect increasing control over emotional impulses as an individual enters adulthood
(Bunge & Wright, 2007). Although this is likely true, the present data suggest that prefrontal
development may enable not just emotion regulation, but the top-down generation of emotions
with increasing cognitive complexity as well.

Second, this work speaks to the role of affective responses in various social cognitive
phenomena. One salient example is the study of attitudes, which have a strong evaluative
component. The present work suggests that not all attitudes are created equal, and could be
classified in terms of the bottom-up or top-down processes from which they arose. This
suggestion fits with research showing that implicit and explicit attitudes depend on some of the
same systems associated here with bottom-up and top-down emotion (Cunningham & Zelazo,
2007).

Third, these data suggest new ways in which bottom-up and top down processes may
play a role in clinical disorders. One possibility is that optimal treatment regimens for
dysfunctional emotions might differ if they were generated primarily by either bottom-up or top-
Bottom-up and Top-down Processes in Emotion Generation

down processes. Bottom-up abnormalities might be most amenable to change via behavioral reinforcement methods that re-shape response tendencies over time (Quirk & Beer, 2006), whereas top-down abnormalities may be best addressed using cognitive methods that restructure one’s consciously accessible appraisals (Ochsner & Gross, 2005). Future translational work could examine this idea in disorders like phobia and panic where bottom-up reactions as opposed to top-down interpretations (of physical sensations) generate problematic negative emotions.

Conclusions and Future Directions

The present study dovetails with the old observation (Hebb & Thompson, 1954) that, “…emotional susceptibility increases with intellectual capacity.” The present data suggest that we are emotional in part because of our intellectual – that is, cognitive – capacities. More broadly, the finding of separable bottom-up and top-down routes for negative emotion generation provides a neural foundation for emotion theories positing multiple kinds of appraisal processes, some of which are bottom-up and triggered reflexively and some of which are top-down and highly cognitive (Scherer, Schorr, & Johnstone, 2001). In so doing, these data suggest new directions for future work, including how bottom-up and top-down processes contribute to positive as well as negative emotions, as well as the roles they play in development, social cognition, and psychopathology.
Acknowledgements

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Bottom-up and Top-down Processes in Emotion Generation

References


Bottom-up and Top-down Processes in Emotion Generation


Bottom-up and Top-down Processes in Emotion Generation


Table 1: Regions showing greater activity during Bottom-up or Top-down emotion generation (i.e. that showed greater relative activity in their direct comparison) or that were active during both (i.e. their conjunction).

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<td>15</td>
<td>-1.55</td>
<td>3.68</td>
<td>4.54</td>
</tr>
<tr>
<td>Posterior Temporal Cortex</td>
<td>29 -67 -41</td>
<td>244</td>
<td>-0.42</td>
<td>3.62</td>
<td>5.11</td>
</tr>
<tr>
<td>Posterior Temporal Cortex</td>
<td>31 -87 -43</td>
<td>17</td>
<td>-1.90</td>
<td>3.70</td>
<td>4.91</td>
</tr>
<tr>
<td>Putamen</td>
<td>-19 5 1</td>
<td>104</td>
<td>-0.56</td>
<td>4.28</td>
<td>4.81</td>
</tr>
<tr>
<td>Putamen</td>
<td>21 9 15</td>
<td>8</td>
<td>0.63</td>
<td>4.28</td>
<td>4.23</td>
</tr>
</tbody>
</table>

**Conjunction of Bottom up and Top-down Emotion Generation**

Amygdala* -17 -9 -11 68 4.45 2.43
Amygdala* -21 5 -27 44 3.19 3.14

Note: BU = Bottom-up; TD = Top-down. TD t and BU t are t-values for comparisons with BU Neutral trials and are presented here for informational purposes. Diff t is for the direct comparison of BU and TD Negative trials with one another. Coordinates are for peak voxel. Voxel resolution is 8 mm$^3$. For reference, t = 1.73 is p < .05; t = 2.54 is p < .01; t = 2.86 is p < .005; t = 3.58 is p < .001; t = 3.88 is p < .0005; t = 4.59 is p < .0001. * Amygdala regions of a priori interest identified at whole brain threshold of p < .05.
Table 2: Regions Correlated With Increases in Self-reported Negative Affect During Bottom-up or Top-down Emotion Generation.

<table>
<thead>
<tr>
<th>Region of Activation</th>
<th>Peak Coordinates</th>
<th>Voxels</th>
<th>BU r</th>
<th>TD r</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bottom-up Emotion Generation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amygdala (dorsal)</td>
<td>33, -3, -5</td>
<td>188</td>
<td>.75</td>
<td>.41</td>
</tr>
<tr>
<td>Amygdala (dorsal)</td>
<td>-29, -1, -11</td>
<td>68</td>
<td>.71</td>
<td>.23</td>
</tr>
<tr>
<td><strong>Top-down Emotion Generation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal Medial Prefrontal Cortex</td>
<td>-1, 49, 29</td>
<td>138</td>
<td>-.02</td>
<td>.64</td>
</tr>
</tbody>
</table>

Note: Coordinates and correlations are for peak voxel. Voxels are 8 mm³. BU = Bottom-up; TD = Top-down; r = Pearson correlation. For reference, r = .44 is p < .05; r = .56 is p < .01; r = .60 is p < .005; r = .68 is p < .001; r = .71 is p < .0005; r = .76 is p < .0001.
Figure Captions

Figure 1. Schematic illustrating the design of the experimental task, which employed two types of stimulus images and two types of instructions. The task is designed so that Bottom-up-Neutral trials provide a baseline that differs from Bottom-up-Negative trials only in terms of the affective nature of the stimulus, and differs from Top-down-Negative trials only in terms of the instruction to construct a high-level cognitive interpretation of the neutral stimulus as aversive. Comparisons of the two emotion-generative trial types with baseline Bottom-up-Neutral trials may therefore identify brain regions involved in either bottom-up or top-down emotional responding.

Figure 2. A. Three-dimensional medial view and blow-up of left amygdala voxels during only bottom-up (orange) or both bottom-up and top-down (blue) emotional responding. B. Axial views of amygdala regions active during only bottom-up (orange) or both bottom-up and top-down (blue) emotional responding. As these panels demonstrate, left amygdala activity was observed in both cases, although overall, greater activity was observed during bottom-up emotion generation. C. BOLD response in the commonly active voxels illustrates comparable activity during both kinds of emotion generation.

Figure 3. Medial (top) and lateral (bottom) views of brain regions active during either bottom-up (hot colors) or top-down (cool colors) emotion generation (see Figure 1 for illustration of underlying contrasts). Three findings are of note. First, bottom-up emotion generation activated lateral occipital and right dorsolateral prefrontal regions implicated in encoding and sustaining attention to visual stimuli. Second, top-down emotion generation activated left temporal, dorsolateral and cingulate regions implicated in working memory and cognitive control, as well as dorsal medial prefrontal regions implicated in mental state attribution. And third, the only region commonly activated was left amygdala, as shown in Figure 2.

Figure 4. Correlations between self-reported negative affect and brain activity during bottom-up (left panels) and top-down (right panels) emotion generation. Green regions illustrate the cluster from the main effect analysis (thresholded at p < .05) within which the correlated regions (shown in hot colors) were found. For the Bottom-up panels, negative affect was calculated as the increase in self-reported negative emotion on Bottom-up Negative as opposed to Bottom-up Neutral trials. For the Top-down panels, negative affect was calculated as the increase in self-reported negative emotion on Top-down Negative as opposed to Bottom-up Neutral trials. As the correlation scatterplots in each panel illustrate, self-reports of negative affect correlated selectively with amygdala activity during bottom-up emotion generation, and with dorsal mPFC activity during top-down emotion generation.
Figure 1

Instruction Type

<table>
<thead>
<tr>
<th>Bottom-Up</th>
<th>Top-Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Look at image and let yourself respond naturally”</td>
<td>“Construct negative interpretation of what’s happening in image”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stimulus Type</th>
<th>Bottom-Up-Negative</th>
<th>Top-Down-Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>Bottom-Up-Neutral</td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regions involved in Bottom-Up emotion generation

Regions involved in Top-Down emotion generation
Figure 2

A. 

B. y = 4  y = 0  y = -4

Region of Overlap

C. BOLD response in overlapping voxels

% Signal Change

Time from trial onset, sec
Figure 3

Greater activity for Top-down

Greater activity for Bottom-up

x = 6

x = -6

Medial

Lateral

p < .00001

p < .001
Figure 4

Bottom-up

Top-Down

Amygdala activity vs. Negative Affect

- Amygdala activity vs. Negative Affect
  - Bottom-up: $r = 0.71$, $p < 0.001$
  - Top-Down: $r = 0.23$, $p < 0.35$

Medial PFC activity vs. Negative Affect

- Medial PFC activity vs. Negative Affect
  - Bottom-up: $r = -0.02$, $p < 1.0$
  - Top-Down: $r = 0.64$, $p < 0.003$