

Sinful pleasures and pious woes? Using fMRI to examine evaluative and hedonic emotion knowledge

Kent M. Lee, ¹ SuhJin Lee, ² and Ajay B. Satpute ¹

¹Department of Psychology, Northeastern University, Boston, MA 02115, USA

²Department of Neurobiology, University of Pittsburgh School of Medicine, Pittsburgh, PA 15213, USA

Correspondence should be addressed to Kent M. Lee, Department of Psychology, Northeastern University, 125 Nightingale Hall, Boston, MA, USA.

E-mail: ke.lee@northeastern.edu

Abstract

Traditionally, lust and pride have been considered pleasurable, yet sinful in the West. Conversely, guilt is often considered aversive, yet valuable. These emotions illustrate how evaluations about specific emotion and belief about their hedonic properties may often diverge. Evaluations about specific emotion may have an important aspect to emotional life (e.g. in emotion regulation, emotion experience and acquisition of emotion concepts). Yet these evaluations are often understudied in affective neuroscience. Prior work in emotion regulation, affective experience, evaluation/attitudes and decision-making point to anterior prefrontal areas as candidates for supporting evaluative emotion knowledge. Thus, we examined the brain areas associated with evaluative and hedonic emotion knowledge, with a focus on the anterior prefrontal cortex. Participants ($N = 25$) made evaluative and hedonic ratings about emotion knowledge during functional magnetic resonance imaging (fMRI). We found that greater activity in the medial prefrontal cortex (mPFC), ventromedial PFC (vmPFC) and precuneus was associated with an evaluative (vs hedonic) focus on emotion knowledge. Our results suggest that the mPFC and vmPFC, in particular, may play a role in evaluating discrete emotions.

Key words: emotion concepts; emotion words; fMRI; emotion evaluation

Pride and lust are ranked among the seven cardinal sins of Western canon (Aquinas, 2006). The belief in the sinfulness of pride and lust stands out because they are emotions that are often considered hedonically pleasant while being evaluated as bad in Western religious tradition. Even today, many people recognize that pride and lust are often evaluated as ‘bad’ emotions despite being believed to be experientially pleasant emotions. Thus, pride and lust offer an intuitive example of how evaluations of emotions and beliefs about their hedonic properties can diverge. Indeed, this divergence exists for a range of different emotions (for discussions see Parrott, 1993; Larsen, 2000; Dweck, 2017; Ford and Gross, 2019).

Evidence of divergence between hedonic and evaluative aspects of emotion suggests that people may place values on different emotions that are distinct from hedonics. These values include attitudes toward specific emotions, a social appropriateness and desirability of these emotions (Eid and Diener, 2001; Wood *et al.*, 2009; Harmon-Jones *et al.*, 2011; Yoon *et al.*, 2018). For instance, some people vary in the extent to which they fear unpleasant emotions such as anger, anxiety and depression. Greater fear of unpleasant emotions is tied to more intense depressive symptoms (Yoon *et al.*, 2018). Moreover, cross-cultural studies have shown that social norms contribute to the desirability of positively and negatively valenced emotions (Tsai *et al.*,

2006) or even fear of a positive emotion (happiness; Joshanloo *et al.*, 2014). Additional work has indirectly demonstrated that people hold beliefs about the usefulness or social acceptability of certain negative emotions, such as anger or shame. For example, in one study, participants tend to upregulate anger when expecting to negotiate with another person, but not when expecting to cooperate with that person (Tamir and Ford, 2012). Further, whether participants reported more frequent encounters with situations that elicited anger vs shame depended on which emotion was socially sanctioned and which was socially condemned in their culture (Boiger *et al.*, 2013). Consistent with norms in their respective countries, US participants tended to report that they encountered situations that elicited anger more than situations that elicited shame. In contrast, Japanese participants tended to report the opposite.

These studies suggest that there is a divergence between evaluative and hedonic aspects of ‘emotion knowledge’. Emotion knowledge refers to a person’s store of beliefs and experiences about an emotion category (for similar treatments see Salovey and Mayer, 1990; Barrett, 2006, 2009; Niedenthal, 2008; Russell, 2009; Lindquist *et al.*, 2015). It includes knowledge about normative views on the hedonic or evaluative properties of that emotion. Consider that, although pride, happiness and lust are normatively assumed to be hedonically pleasurable in Western contexts,

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studies have found that they may be evaluated negatively in certain cultural contexts (Eid and Diener, 2001 ; Stenstrom and Curtis, 2012 ; Joshanloo *et al.*, 2014; see also Aquinas, 2006). Conversely, although guilt, shame and anger are often assumed to be hedonically unpleasant, studies have found they may be evaluated as positive in specific cultural contexts (Eid and Diener, 2001 ; Tamir and Ford, 2012 ; Boiger *et al.*, 2013).

For neuroscience, in particular, research on evaluative vs hedonic emotion knowledge raises questions about their neural bases and the extent to which they overlap. Studies have implicated prefrontal cortical areas including the medial prefrontal cortex (mPFC), ventromedial prefrontal cortex (vmPFC) and right dorso-lateral prefrontal cortex (dlPFC) in judging the valence of affective stimuli (Anderson *et al.*, 2003; Small *et al.*, 2003; Grimm *et al.*, 2006). Further, activity in the mPFC and dlPFC are correlated with judgments of valence but not judgments of arousal associated with emotion-related words (e.g. distressed, excited, content, bored, idle, etc.; Posner *et al.*, 2009). Several multivariate studies have also found evidence that areas in the anterior mPFC, among others, are involved in representing stimulus valence across sensory modalities (Baucom *et al.*, 2012; Chikazoe *et al.*, 2014; Skerry and Saxe, 2014; Bush *et al.*, 2018; Kim *et al.*, 2020; Shinkareva *et al.*, 2020). Studies on attitudes and evaluations similarly suggest that the mPFC and vmPFC are associated with evaluative judgments. These include making good–bad judgments about concepts like murder, happiness or gun control (Cunningham *et al.*, 2004), agreement or disagreement with evaluative statements (Zysset *et al.*, 2002; Schroeter *et al.*, 2010) and judging whether two evaluations are compatible (e.g. ‘Chris likes parties’ and ‘parties are good’; Wood *et al.*, 2005). Other studies have shown mPFC activation during moral (Greene *et al.*, 2001, 2004; Moll *et al.*, 2001) and aesthetic judgments (Jacobsen *et al.*, 2006; Kirk *et al.*, 2009; Zhang *et al.*, 2016, 2017). Finally, damage to the vmPFC, in particular, produces disruptions in valuation during decision-making, such as deficit in valuing future (vs immediate) rewards, insensitivity to punishment, impaired reversal learning and erratic preference judgments (Bechara *et al.*, 1994, 1997; Fellows and Farah, 2003, 2007). Collectively, these studies demonstrate that anterior prefrontal areas support judgments concerning valence across different domains.

We were particularly interested in the vmPFC’s role in focusing on evaluative (vs hedonic) dimensions of emotion knowledge. Studies have shown that vmPFC regulates subcortical structures involved in affective experience such as the amygdala and striatum (Roy *et al.*, 2012; Rae *et al.*, 2015). Other work has further suggested that the vmPFC, along with and dlPFC are involved in inhibitory control and affective regulation (Cunningham and Zelazo, 2007; Goldin *et al.*, 2008; Kober *et al.*, 2010). Meanwhile, studies in value-based decision-making have implicated the vmPFC in evaluating the healthiness and taste of foods when choosing between healthy and unhealthy foods (Hare *et al.*, 2009; Nook and Zaki, 2015 ; Schmidt *et al.*, 2018). Notably, for self-reported dieters, both the ratings of healthiness and taste moderated the relationship between vmPFC and food choice during successful self-control, that is, when choosing less tasty but healthy foods over tasty but unhealthy foods (Hare *et al.*, 2009). In contrast, only taste ratings moderated the relationship between the vmPFC and food choice during unsuccessful self-control (choosing tasty but less healthy foods over healthy foods).

These findings (Hare *et al.*, 2009) suggest that the vmPFC is involved in more than the representation of hedonic value. Instead, it is consistent with the hypothesis that the vmPFC plays

a role in evaluation more broadly and that it integrates hedonic and other pertinent information (e.g. healthiness of a food) during decision-making. Further consistent with this hypothesis, vmPFC activity to healthy and unhealthy foods is also affected by the foods’ popularity (Nook and Zaki, 2015). When participants were blind to how their peers evaluated different foods, vmPFC activation was greater when viewing unhealthy vs healthy foods. However, once participants were presented with alleged peer ratings (like vs dislike) about the popularity of different foods, vmPFC activity tracked with popularity rather than healthiness or unhealthiness. Together, these studies suggest that the vmPFC, alongside the dlPFC, plays an important role in evaluative focus in certain domains. However, little is known about neural responses when the evaluative focus is on emotion knowledge.

To determine which brain regions were engaged when participants focused on evaluative vs hedonic dimensions of emotion knowledge, participants made judgments about the evaluative (bad vs good) and hedonic (unpleasant vs pleasant) properties of different emotion categories. These categories were represented by emotional words. Using emotion words as stimuli enabled us to emphasize the processes involved in representing emotion knowledge over the processes that generate affective experiences. Indeed, there are now hundreds of studies that have examined the neural correlates of affective and emotional experiences which likely engage a wide variety of processes including those related to the generation of affect, retrieval of emotion knowledge and more (Vytal and Hamann, 2010 ; Satpute *et al.*, 2013; Lindquist *et al.*, 2016). However, few studies have specifically examine emotion knowledge separately from affect generation, let alone neural activity associated with the evaluation of emotions in particular.

Method

Participants

A total of 25 right-handed, native-English speaking participants (11 females and 14 males), aged 21–40 years ($M = 29.84$, $s.d. = 5.46$), took part in the study. Participants received \$40 per hour for taking part in the scanning session. Participants were included in the study if they were between the ages of 18 and 55, were native English speakers, were right-handed, had no metal in their bodies and had no history of psychiatric illness. Participants provided written informed consent prior to taking part in the study. All procedures were approved by the institutional review board at the California Institute of Technology.

Experimental task

To investigate neural activity associated with representing emotion words on evaluative vs hedonic dimensions, we designed a task with a 2 (Task: Evaluative vs Hedonic) by 10 (Emotion Category: Anger, Disgust, Fear, Guilt, Sad, Calm, Excited, Happy, Lust and Pride) repeated measures factorial design. The ten emotion words were chosen to have a balance of positively and negatively valenced words presumed to show variability in the agreement of their evaluative vs hedonic traits based on prior behavioral work. For example, whereas anger, guilt, lust and pride are commonly thought to diverge in their hedonic and evaluative aspects (Eid and Diener, 2001 ; Stenstrom and Curtis, 2012 ; Tamir and Ford, 2012; Boiger *et al.*, 2013), the other emotions might be expected to show less divergence. In a separate set of behavioral studies, we found that the valuation of emotion depended on the valuation dimension (evaluative vs hedonic) and emotion category in question (Lee *et al.*, under review). Certain emotions such as lust, pride, guilt, anger among others showed divergence between

their evaluative and hedonic valence, whereas others were less so (e.g. misery, joy and awe).

In the experimental trials, participants were first presented with the rating scale before one of ten emotion words appeared on screen for 4 s. During this 4 s window, participants were instructed to make a rating. In one block, participants rated the words on the extent to which they thought the emotion was evaluatively good or bad in general. In the other block, participants rated the words on whether the emotion described was hedonically pleasant or unpleasant in general. Participants provided a rating along a continuous rating scale (a line with a cursor) with 'good' (or 'pleasant') (0) and 'bad' (or 'unpleasant') (1) being the other anchor. For example, a rating at the midpoint of the scale would be recorded as 0.50, which is functionally a response of 'neither.' For ease of interpretability, participants' evaluative and hedonic ratings were reverse scored such that bad/unpleasant = 0 and good/pleasant = 1. This was done by subtracting the ratings from 1.

Participants also completed a standard odd–even task for use as a baseline task (Stark and Squire, 2001). In the baseline task, participants were presented with a number (1, 3, 4, 5, 6 or 8) and made a response by making a button press on the trackball if the number was '5.' In total, participants completed 8 experimental blocks, repeating the evaluative and hedonic blocks twice within a run across 2 runs for a total of 40 emotion word trials for each type of judgment (evaluative vs hedonic). Additionally, prior to entering the scanner, participants completed a total of four practice blocks, with evaluative and hedonic ratings being repeated twice within a run. Block order was randomized.

Apparatus

Participants were scanned using a Siemens TIM Trio (Erlangen, Germany) 3T scanner equipped with a 32-channel head coil. Functional image acquisition was done using a T2*-weighted echo planar imaging (EPI) pulse sequence (TR = 1 s, TE = 3 s, flip angle = 60°, 2.5 mm isotropic resolution, interleaved transverse acquisition). Anatomical image acquisition was done using a T1-weighted sequence (TR = 2.4 s, TE = 2.6 s, flip angle = 8°, 1 mm isotropic resolution). We presented the task using a projector onto a screen that participants could see via a mirror attached to the head coil.

Data Analysis

We used fmrip (<https://fmrip.readthedocs.io/en/stable/index.html>) to preprocess the functional images. We coregistered the functional images with each participant's T1-weighted structural image, applied motion correction and slice-time correction before and normalized the functional images using the MNI-ICBM152 template before applying spatial smoothing (6 mm full width half max). First and second level analyses were conducted in NeuroElf v1.1 rc2 (<http://neuroelf.net/>) using MATLAB version R2018b. To examine neural correlates of the evaluative vs hedonic qualities of emotion knowledge, we first conducted analyses that modeled the two functional runs as a general linear model (GLM) with a separate regressor for the evaluative and hedonic rating conditions and a single nuisance regressor accounting for subject head movement. The GLM convolved each regressor with the canonical hemodynamic response function. We then computed subtraction contrasts from the first-level GLMs (Evaluative > Hedonic) for second-level group maps. We used AlphaSim Monte Carlo simulation (smoothness was estimated from the data) to correct for family-wise error (FWE) at the voxel level

across the whole brain using a voxel-wide threshold at $P < 0.005$, $t > 2.80$, FWE $P < 0.05$.

Results

Behavioral Results

To examine whether participants distinguished between evaluative and hedonic aspects of emotion knowledge, we first examined their ratings. Based on previous behavioral studies (Lee et al., under review), we expected a two-way interaction between the type of rating and the emotion category. Thus, we conducted a 2 (Judgment type: Evaluative vs hedonic) $\times$ 10 (Emotion category: anger, disgust, fear, guilt, sad, calm, excited, happy, lust, pride) repeated measures ANOVA. Consistent with our hypothesis, we found a significant interaction between judgment type and emotion, $F(9, 207) = 7.51$, $P < 0.001$, $\eta^2 = 0.25$. We also found a significant main effect of emotion, $F(9, 207) = 145.09$, $P < 0.001$, $\eta^2 = 0.86$. We did not find a main effect of judgment type, $F(1, 23) < 0.01$, $P = 0.96$, $\eta^2 < 0.01$. The main effect of emotion category will be interpreted in the context of the significant interaction.

Post-hoc comparisons revealed significant pairwise differences between evaluative and hedonic ratings for guilt, excited, lust and pride. Participants rated guilt to be more 'good' ($M = 0.18$, s.d. = 0.19) than 'pleasant' ($M = 0.11$, s.d. = 0.12), $t(24) = 2.27$, $P = 0.03$. Conversely, participants rated excited to be more 'pleasant' ($M = 0.89$, s.d. = 0.11) than 'good' ($M = 0.85$, s.d. = 0.12), $t(24) = 2.58$, $P = 0.02$. Similarly, participants rated lust as being more 'pleasant' ($M = 0.55$, s.d. = 0.26) than 'good' ($M = 0.42$, s.d. = 0.27), $t(24) = 3.29$, $P < 0.01$. Finally, participants rated pride to be more 'pleasant' ($M = 0.70$, s.d. = 0.20) than 'good' ($M = 0.62$, s.d. = 0.25), $t(24) = 2.32$, $P = 0.03$. Notably, differences were evident mostly in emotions (guilt, lust and pride) that are commonly viewed as having divergent evaluative and hedonic valence in Western culture. Additionally, we examined the response times for participants' ratings to examine whether task difficulty might account for any differences between evaluative vs hedonic ratings. Participants' response times did not significantly differ between evaluative and hedonic ratings, $F(1, 23) = 0.19$, $P = 0.67$, $\eta^2 = 0.01$. Thus, task difficulty unlikely accounts for our results.

In sum, the behavioral findings suggest that participants adopted an evaluative focus when making good/bad judgments and a hedonic focus when making pleasant/unpleasant judgments of emotion categories. To be sure, we did not expect mean differences in ratings to occur for each and every emotion category. Indeed, it stands to reason that even if evaluative and hedonic ratings are similar for certain emotion categories, participants may nonetheless be focusing on and retrieving different informational dimensions. For example, that happiness was rated similarly on both evaluative and hedonic rating dimensions does not mean that participants were processing happiness in the same way. Thus, these findings suggest that more simply that participants followed task instructions: they adopted an evaluative focus when judging emotion concepts along the 'good or bad' dimension, and a hedonic focus when judging emotion concepts along the 'pleasant or unpleasant' dimension, across emotion concepts.

Neuroimaging results

Our goal was to examine the extent to which neural activity in frontal areas would be associated with accessing evaluative

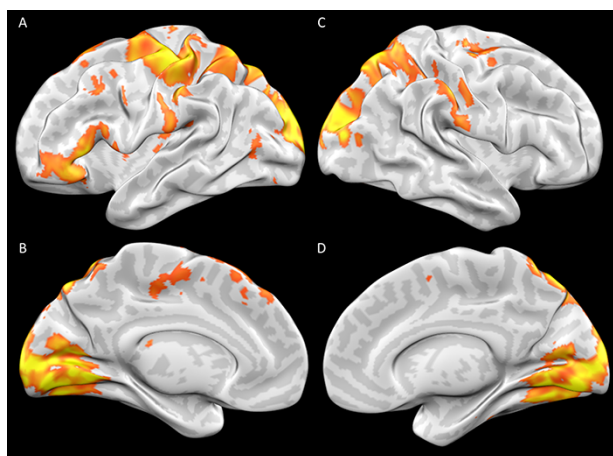


Fig. 1. Activation during evaluative and hedonic judgments of emotion concepts relative to baseline. Figure 1A shows a lateral view and Figure 1B shows a medial view of activation in the left hemisphere associated both evaluative and hedonic judgments. Figure 1C shows a lateral view and Figure 1D shows a medial view of activation in the right hemisphere during both evaluative and hedonic judgments. All results are FWE corrected at $P < 0.05$ using a nominal voxel-wise threshold of $P = 0.005$ and cluster-extent threshold of $k = 134$.

(vs hedonic) emotion knowledge. First, we compared neural activity during the task to baseline to see whether the task would engage salience areas typically associated with affect. Consistent with our expectations, we did not find that making ratings about emotion words engaged the amygdala, anterior cingulate cortex, the insula, the ventral striatum or other areas commonly associated with generating affective experiences. Rather, we found activation in a number of regions including the left inferior frontal gyrus, in an area associated with a variety of processes including language, alongside general task-positive engagement (Figure 1). We also found activation in a number of visual and motor areas that included primary visual cortex and extrastriate visual areas in the cuneus, as well as the pre-central and post-central gyri (Figure 1). This finding is potentially attributable to different sources including the increased visual (processing semantically meaningful words vs single digit numbers) and motor demands of the task compared to baseline (moving the trackball when making ratings in the experimental vs making a button press during the baseline task). Together, the results are consistent with the notion that the emotion judgment task drew more on areas involved in linguistic processing rather than areas associated with affective experience.

To examine the brain areas associated with evaluative (vs hedonic) emotion knowledge, we contrasted conditions for evaluative vs hedonic rating blocks. When participants made evaluative (vs hedonic) judgments, we found a significant cluster of activation in the anterior mPFC, $k = 347$; peak voxel at $[21, 66, 0]$; $t(24) = 3.28$, $P < 0.005$ (Figure 2A) that included the vmPFC, $k = 22$; peak voxel at $[6, 60, -15]$; $t(24) = 3.07$, $P < 0.005$ (Figure 2B). During evaluative (vs hedonic) judgments, we also found greater activity in the midline precuneus, $k = 108$; peak voxel at $[6, -57, 42]$; $t(24) = 3.23$, $P < 0.005$ (Figure 2B). Access to evaluative emotion knowledge was associated with increased activity in these areas (Figure 2C). Conversely, when participants made hedonic (vs evaluative) judgments, we found increased activation in the left post-central gyrus, $k = 107$; peak voxel at $[-39, -21, 60]$; $t(24) = 3.29$, $P < 0.005$. Given that we did not find a significant difference in participants' response times in the evaluative and

hedonic blocks, task difficulty is unlikely to account for these findings. Overall, our results point to other mPFC and precuneus areas being important in evaluative vs hedonic emotion knowledge in general.

Discussion

Emotion knowledge is multifaceted (Barrett, 2006; Tsai *et al.*, 2006; Niedenthal, 2007; Tsai, 2007; Lindquist *et al.*, 2015; Hoemann *et al.*, 2020) and believed to play an important role in shaping affective experiences, whether through regulation (Izard *et al.*, 2011; Torre and Lieberman, 2018) or emotion construction (Barrett, 2006, 2009; Lindquist, 2013). Indeed, multiple processes, including emotion knowledge, are thought to come online when experiencing discrete emotions (Lazarus, 1991; Tsai, 2007; Barrett, 2009; Tamir, 2009; Roseman, 2011; Lindquist, 2013). Emotion knowledge likely comes online alongside other processes involved in directing attention, driving autonomic changes, preparing for or initiating motor responses, etc. (Barrett *et al.*, 2007; Satpute *et al.*, 2013). Yet, there is a dearth of affective neuroscience studies that identify brain regions that are engaged when focusing on different dimensions of emotion knowledge vs other components involved in emotion experiences. For example, many studies investigate the brain basis of positive and negative valence by examining brain activity following various affective stimuli (e.g. videos, images, faces; Phan *et al.*, 2002; Lindquist *et al.*, 2016). However, this approach does not differentiate processes related to emotion knowledge vs affect generation and conflate evaluative (good and bad) and hedonic (pleasant and unpleasant) aspects of emotion into valence.

Our current functional magnetic resonance imaging (fMRI) study addresses this gap by identifying functional activation patterns associated with focusing on evaluative and hedonic emotion. Our results showed that focusing on evaluative (vs hedonic) aspects of emotion knowledge was associated with greater activity in the anterior mPFC, vmPFC and midline precuneus. Importantly, these areas were not engaged when participants completed the rating task in general. Instead, the task engaged areas consistent with the visual, motor, and linguistic demands of making ratings about words. Moreover, we did not find activity in areas often associated with affective processing such as the amygdala, anterior cingulate cortex, the insula and the ventral striatum. These findings suggest that the areas that may be involved in generation of affect vs emotion knowledge (Satpute *et al.*, 2013). Overall, our results suggest that the anterior mPFC and the precuneus may play a role in accessing evaluative emotion knowledge. This interpretation lines up with prior work showing that regions in the anterior mPFC are engaged during evaluation more generally (Zysset *et al.*, 2002; Cunningham *et al.*, 2004; Wood *et al.*, 2005; Hampton *et al.*, 2006; Schroeter *et al.*, 2010).

Of course, one limitation of our study is that, although our instructions were intended to be as general as possible so as not to bias participants' ratings, emotion knowledge is both rich and highly contextualized (Barrett, 2006; Tsai *et al.*, 2006; Niedenthal, 2007; Tsai, 2007; Lindquist *et al.*, 2015; Hoemann *et al.*, 2020). Even within evaluative and hedonic emotion knowledge, there are likely different aspects that are embedded within specific contexts—just like other forms of concept knowledge (Barsalou, 2009; Yee and Thompson-Schill, 2016; Yee, 2019). For example, evaluative emotion knowledge about whether an emotion is good or bad will likely change depending on the context (e.g. happiness might be good during a celebration but bad during a funeral). The good-bad dimension might include additional subdivisions into

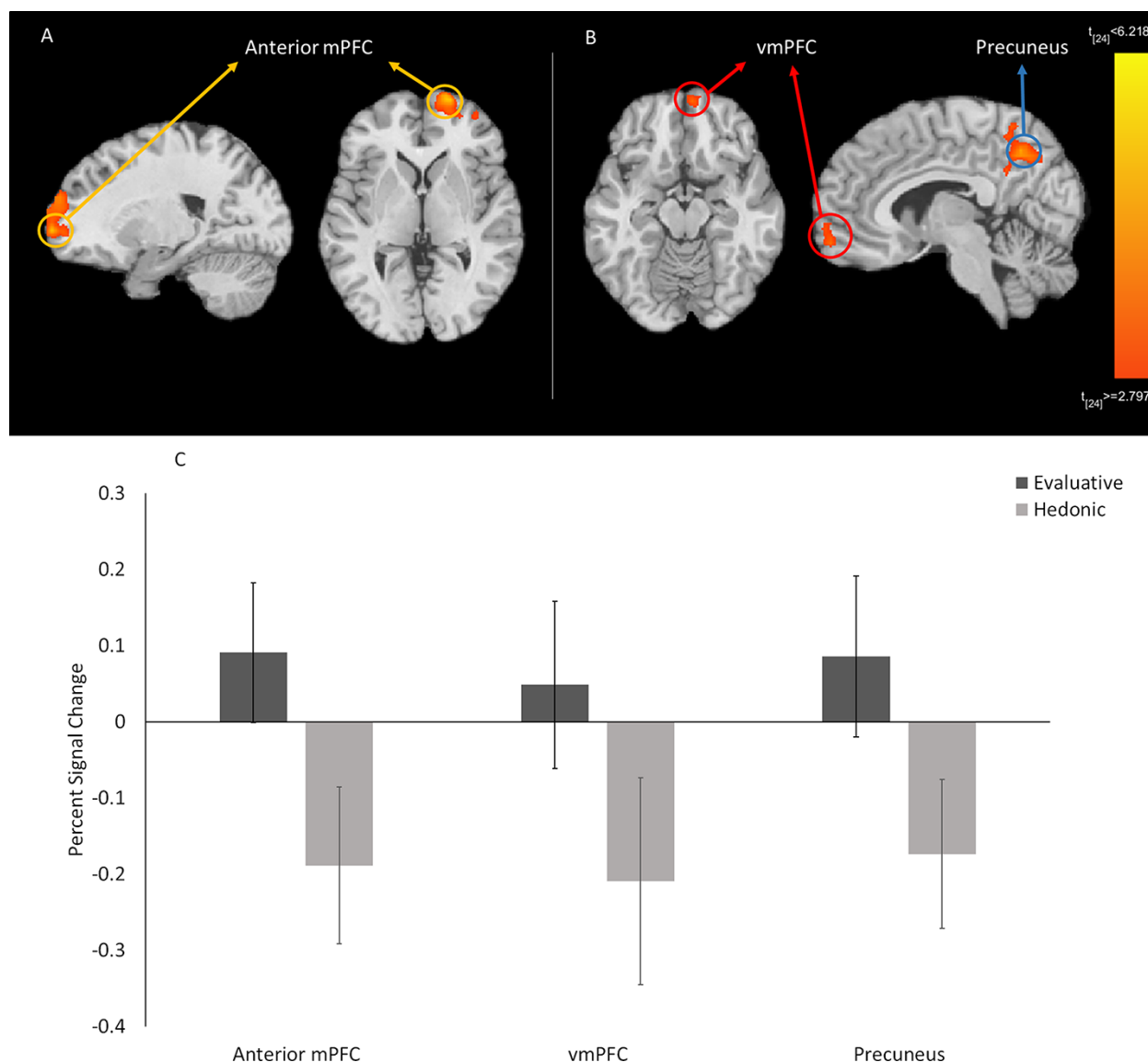


Fig. 2. Anterior prefrontal and precuneus activation during evaluative > hedonic judgments. Figure 2A shows the cluster of activation in the anterior medial prefrontal cortex (mPFC) in the right hemisphere, while Figure 2B shows clusters of activation in the ventromedial prefrontal cortex and midline precuneus. Peak voxels are circled. All results are FWE corrected, $P < 0.05$, voxel-wise $P = 0.005$, k -threshold = 105. Figure 2C shows neural activity in the mPFC, the ventromedial PFC (vmPFC) and precuneus during evaluative vs hedonic judgments. Note that the cluster of activation in the vmPFC is not statistically independent from the anterior mPFC, as it was part of larger cluster of activation with the peak being in the anterior mPFC. Error bars reflect 95% confidence intervals. Effects should be interpreted with caution.

appropriateness, usefulness or morality. Given our instructions, we cannot be certain whether participants made their emotion judgments with reference to specific situation or in a situation-general way. For these reasons, we suggest the more limited interpretation that the areas of the anterior medial prefrontal cortex and precuneus may be relevant when the focus is on evaluating emotion, but future work is needed to address exactly how the contents of different dimensions of emotion knowledge are represented.

While our study asked participants to provide evaluative ratings of emotion in general, we did not examine the source of their evaluations. Indeed, participants may have based their judgments on beliefs they thought that other people might hold (i.e. normative beliefs), beliefs that they personally hold or a combination of both. Moreover, it seems plausible that emotion evaluations will likely be driven by different sources for different

people depending, for example, on the extent to which one's personal beliefs are shared with the cultural milieu that underlies their perceptions of normative beliefs or are influenced from other sources (e.g. in cases when one might reject certain cultural or religious institutions in favor of others, and then re-evaluate emotions accordingly). Going forward, a richer behavioral examination of the sources of emotion evaluations and how they vary across individuals would be an important step toward developing a more thorough examination of how the brain represents emotion evaluations and emotion knowledge more generally.

Implications

Our findings point to a question for future work examining how people develop emotion knowledge and evaluations about emotion categories. For example, when do children develop

evaluative emotion knowledge? Children acquire knowledge about emotion categories (e.g. anger, fear, disgust, etc.) over the course of development (Bridges, 1932; Camras, 1992; Russell and Widen, 2002; Widen *et al.*, 2015; Nook *et al.*, 2017; Hoemann *et al.*, 2019, 2020; Shablack and Lindquist, 2019). For instance, it is not until two to three years of age that children begin to reliably categorize faces based on prototypical emotion categories (Widen, 2016; Hoemann *et al.*, 2019). Notably, two- to three-year old children's ability to consistently categorize prototypical emotion faces above and beyond valence depends on the presence of emotion labels (Russell and Widen, 2002). In contrast, young infants at three to four months of age are only able to categorize emotional faces based on valence (Walker-Andrews, 1997). Even then, these infants are only able to reliably do so when there is accompanying information such as vocal expressions.

Relevant for questions about the acquisition of emotion evaluative knowledge, Atzil and Gendron (2017) have noted that the ability of children and adolescents to regulate their emotions coincides with the development of the default mode network. The default mode has been proposed to support emotion knowledge (Satpute and Lindquist, 2019). The ability to successfully regulate emotion increases linearly with age (McRae *et al.*, 2010). This coincides with linear increases in the strength of functional connectivity between the mPFC and posterior cingulate cortex (PCC) over the course of adolescence (Fair *et al.*, 2008). Intriguingly, the mPFC and PCC are earliest nodes in a nascent default mode network to show functional connectivity with other areas at early stages of development (Gao *et al.*, 2009). By one year of age, these two areas are already highly connected to other areas. Given that our finding implicates the mPFC and the precuneus in evaluative emotion knowledge, researchers might begin to investigate how the ability to evaluate emotions changes with developmental changes in connectivity between the mPFC and the PCC/precuneus and other default mode areas.

Our results may also help clarify the role of prefrontal areas in emotion regulation. Many studies of emotion regulation have focused on activity in the mPFC—the vmPFC in particular—during emotion regulation (Harenski and Hamann, 2006; Urry *et al.*, 2006; Koenigsberg *et al.*, 2009; McRae *et al.*, 2010, 2012; Dolcos *et al.*, 2014). However, a meta-analysis of studies on the neural correlates of emotion regulation did not find that the vmPFC was consistently activated during reappraisal (Buhle *et al.*, 2014). Instead, prefrontal areas associated with reappraisal included the lateral mPFC and the dorsomedial PFC, which have been implicated in cognitive control. Yet, an important gap in the literature on emotion regulation in general is that studies generally tell participants when and how to regulate their emotions. In turn, these studies rarely examine decisions during the emotion regulation process.

In contrast, in everyday life emotion regulation involves a series of decisions. For example, a person decides whether to regulate or experience an instance of emotion. If deciding to regulate, they might then choose between regulation strategies (e.g. distraction vs reappraisal; see Sheppes *et al.*, 2011, 2014). Our results raise the possibility that one role of the vmPFC in emotion regulation is supporting the decision-making process. Specifically, the vmPFC might be involved in evaluation of emotions during decisions to regulate. While speculative, this would be consistent with the vmPFC's established role in decision-making (Bechara *et al.*, 1994, 1997; Fellows and Farah, 2003; Grabenhorst and Rolls, 2011) and in evaluation (Zysset *et al.*, 2002; Cunningham *et al.*, 2004;

Hare *et al.*, 2009; Nook and Zaki, 2015). Indeed, studies on reward learning and decision-making that have implicated anterior prefrontal areas with valuation (O'Doherty *et al.*, 2001a, 2001b; Dom *et al.*, 2005; Lin *et al.*, 2012; Gross *et al.*, 2014). Similarly, lesions to anterior prefrontal areas produce deficits in evaluative results in disruptions in reward-learning (Hornak *et al.*, 2004; Tsuchida *et al.*, 2010; Vaidya and Fellows, 2016), decision-making (Bechara *et al.*, 1997; Clark *et al.*, 2008; Moretti *et al.*, 2009; Koenigs *et al.*, 2010; but see Sanfey *et al.*, 2003) and judging the appropriateness of behaviors (Beer *et al.*, 2003; Berlin *et al.*, 2004; Leopold *et al.*, 2012; Cameron *et al.*, 2018).

Thus, future work might examine whether the vmPFC's role in emotion regulation involves supporting decision-making during voluntary regulation. If so, then one might expect greater activity in the vmPFC when participants are faced with a decision to regulate or not. In contrast, if the vmPFC's involvement is more tied to processes involved in regulation itself, vmPFC activity might be associated with a specific regulatory strategy or regulation success. Emotion regulation likely involves a number of processes, such as evaluating one's affective state and current situation, categorizing an instance of emotion, reappraisal, etc. Investigating and distinguishing between these processes and their neural bases during voluntary emotion regulation may offer novel insights into the mechanisms of emotion regulation.

Conclusion

People hold evaluations about specific emotions, just as they hold evaluations about external events or other internal mental states. And they distinguish evaluations about specific emotions from beliefs about the hedonic experience of those same emotions. We find evidence that the prefrontal areas support evaluative (vs hedonic) emotion knowledge in our study. These prefrontal areas and the precuneus show increased activation when participants evaluate the goodness or badness of emotions compared to when they judge the pleasantness or unpleasantness of these emotions.

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Conflict of interest

The authors declared that they had no conflict of interest with respect to their authorship or the publication of this article.

Supplementary data

Supplementary data is available at SCANonline.

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