Neural Dissociations in Attitude Strength:

Distinct Regions of Cingulate Cortex Track Ambivalence and Certainty

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Abstract

People's behaviors are often guided by valenced responses to objects in the environment. Beyond positive and negative evaluations, attitudes research has documented the importance of attitude strength – qualities of an attitude that enhance or attenuate its impact and durability. Although neuroscience research has extensively investigated valence, little work exists on other related variables like metacognitive judgments about one's attitudes. It remains unclear, then, whether the various indicators of attitude strength represent a single underlying neural process or whether they reflect independent processes. To examine this, we used fMRI to identify the neural correlates of attitude strength. Specifically, we focus on ambivalence and certainty, which represent meta-cognitive judgments that people can make about their evaluations. Although often correlated, prior neuroscience research suggests that these two attributes may have distinct neural underpinnings. We investigate this by having participants make evaluative judgments of visually presented words while undergoing fMRI. After scanning, participants rated the degree of ambivalence and certainty they felt regarding their attitudes toward each word. We found that these two judgments corresponded to distinct brain regions' activity during the process of evaluation. Ambivalence corresponded to activation in anterior cingulate cortex, dorsomedial prefrontal cortex, and posterior cingulate cortex. Certainty, however, corresponded to activation in unique areas of the precuneus/posterior cingulate cortex. These results support a model treating ambivalence and certainty as distinct, though related, attitude strength variables, and we discuss implications for both attitudes and neuroscience research.

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Forming, using, and expressing evaluations is a key feature of social life. Whether these evaluations are of controversial political issues, everyday decision options, or other individuals or groups of people, the ways in which they come to be, change, and guide behavior has been an enduring research pursuit in social psychology. Although attitudes and evaluative judgments have been studied extensively in neuroscience (for reviews, see Cunningham & Luttrell, 2015; Cunningham & Zelazo, 2007; Falk & Lieberman, 2013; Knutson, Delgado, & Phillips, 2008), the existing research has focused primarily on attitudes' valence – whether a person evaluates something as positive or negative. However, years of social psychological research have highlighted an additional important factor – attitude strength (see Petty & Krosnick, 1995). In the present paper, we extend the current neuroscience literature on evaluations with an in-depth investigation of two attitude strength indicators as they relate to the brain. In particular, we examine neural markers of attitude certainty and ambivalence and the degree to which these two specific attitude strength indicators demonstrate independence at the level of the brain. In doing so, we can better understand the uniqueness of attitude strength variables despite their sometimes overlapping effects.

This neuroscientific approach to studying attitude strength accomplishes at least three goals in developing psychological theory. First, by bringing the rich social psychological literature on attitude strength into the domain of neuroscience, we can develop a more nuanced understanding of the neural processes underlying evaluation. Second, using neuroimaging methods can also help address questions in the attitude strength literature itself. Finally, a social neuroscience perspective in studying attitude strength offers the opportunity to bridge seemingly disparate literatures to identify core processes that connect attitudinal processes to others like memory and decision-making.

Attitude Concepts

An attitude is a relatively stable internal set of evaluative representations of a particular object. In addition to the valence, however, attitudes are also characterized by various structural elements and meta-cognitive appraisals. Structural aspects of attitudes include the relative balance of positive and negative information connected to the attitude object (i.e., “ambivalence”) and the strength of association among these representations (i.e., “accessibility”; Petty, Briñol, & DeMarree, 2007). These representations are used to generate one’s evaluation – a present-moment appraisal of whether a particular stimulus or thought is judged to be good or bad (see Cunningham & Zelazo, 2007). For instance, someone might have a mix of positive and negative associations with *chocolate* (structural ambivalence), and these associations might be especially strongly and readily connected to the topic of *chocolate* in memory (accessibility; Newby-Clark, McGregor, & Zanna, 2002).

In addition to these structural features, several meta-cognitive appraisals of the evaluation are important as well. These meta-cognitive appraisals include perceptions of certainty and feelings of evaluative conflict (Petty, Briñol, Tormala, & Wegener, 2007). Notably, these meta-cognitive judgments are a function of both the structural aspects of the attitude (having both positive and negative features represented or having little stored knowledge to inform an evaluation) and aspects of the current situation (not being able to resolve whether the positive or negative features are more relevant at any given moment or not having clear access to relevant knowledge; see Rucker, Tormala, Petty, & Briñol, 2014; Smith, Fabrigar, MacDougall, & Wiesenthal, 2008; van Harreveld, Nohlen, & Schneider, 2015). Returning to the previous example, although someone might evaluate *chocolate* positively overall, he might not feel especially confident in that positive evaluation.

These structural and meta-cognitive features are often associated with an attitude's strength – the extent to which an attitude guides relevant behavior and resists change (Krosnick & Petty, 1995). The subjective perceptions of relevant attitude features, however, are especially important in driving their effects. For instance, although attitude-relevant thought and accessibility are important determinants of strength, merely perceiving oneself to have thought about a topic or perceiving accessibility, regardless of actual thought or accessibility, produces the same effects (Barden & Petty, 2008; Barden & Tormala, 2014; Haddock, Rothman, Reber, & Schwarz, 1999; Tormala, Clarkson, & Henderson, 2011; Wan, Rucker, Tormala, & Clarkson, 2010). The present research thus focuses on subjective, meta-cognitive indicators of an attitude's "strength," and in particular, we consider two widely studied meta-cognitive appraisals: ambivalence and certainty.

Ambivalence

As noted earlier, although people can have a relatively unambivalent representation of some object (e.g., serial killers are only bad), people often represent both positive and negative reactions in their attitude representations (e.g., chocolate has both positive and negative qualities). In many situations, one valence trumps the other either because it is more strongly represented in the stored attitude or because it is more accessible in the moment (e.g., having a positive evaluation of chocolate when one is hungry or a more negative evaluation when one is trying to lose weight). Even when one valence more strongly informs a momentary evaluation, people may still have a sense of *subjective ambivalence* when their evaluation is built upon strong, accessible positive and negative features (Newby-Clark et al., 2002; Priester & Petty, 1996). People often refer to such instances as "feeling conflicted." Attitudes accompanied by greater feelings of subjective ambivalence are less predictive of attitude-consistent behavior and are especially likely to change and prompt information processing – all important markers of attitude strength (Conner & Armitage, 2008; van Harreveld et al., 2015).

Notably, by virtue of its metacognitive nature, subjective ambivalence can depend on a host of influences beyond the objective conflict between positive and negative reactions. For example, even at the same level of objective ambivalence, subjective ambivalence can depend on the anticipation of conflict (Priester, Petty, & Park, 2007), a pending decision (e.g., van Harreveld, van der Plight, & de Liver, 2009), the attitudes one wishes he or she had (DeMarree, Wheeler, Briñol, & Petty, 2014), bodily cues (Schneider, Eerland, van Harreveld, Rotteveel, van der Plight, van der Stoep, & Zwaan, 2013), as well as the attitudes that other people hold (Priester & Petty, 2001). Thus, subjective ambivalence is a unique metacognitive appraisal of one's attitude whose inherent discomfort signals attitudinal weakness.

Certainty

Attitude *certainty* reflects a meta-cognitive judgment about the perceived validity of an expressed evaluation (Gross, Holtz, & Miller, 1995). Like ambivalence, certainty reflects an attitude's strength whereby greater certainty is associated with outcomes indicative of stronger attitudes. Attitudes held with higher degrees of certainty are more predictive of behavior and more resistant in the face of persuasive messages (Rucker et al., 2014).

The Dimensions of Attitude Strength Indicators

In the present research, we aimed to investigate the degree to which ambivalence and certainty are distinct attitude strength indicators at the level of the brain. To better understand the relative independence of these variables, we can look to a debate in the broader attitude strength literature. For some time, psychologists debated whether or not all indicators of attitude strength (including certainty and ambivalence as well as others such as accessibility, importance, and knowledge) reflected a single latent "attitude strength" construct, particularly because these indicators predicted similar outcomes and were often highly inter-correlated. That is, for example, since people who place importance on a topic also tend to be highly knowledgeable and because each of these variables is associated with greater attitude-consistent behavior, should we consider them separate constructs or merely redundant indicators of a broader notion of "strength"?

Prompted by this question, many researchers presented the results of factor analyses and principal component analyses attempting to identify a reliable factor structure for attitude strength indicators (Abelson, 1988; Alwitt & Berger, 1993; Bass & Rosen, 1969; Bassili, 1996; Erber, Hodges, & Wilson, 1995; Pomerantz, Chaiken, & Tordesillas, 1995; Prislin, 1996). These analyses were motivated by an assumed latent structure underlying these variables. In other words, do importance and knowledge load on the same factor or on separate factors from each other? An alternative perspective, however, was that all individual attitude strength variables are unique and reflect independent qualities of an evaluation (Krosnick, Boninger, Chuang, Berent, & Camot, 1993; Visser, Bizer, & Krosnick, 2006). To continue the example, importance and knowledge have unique properties despite other indications of similarity (and the same for each individual strength variable).

The Independence of Ambivalence and Certainty

Consistent with the latter perspective, we argue that ambivalence and certainty are distinct from one another (see also Clarkson, Tormala, & Rucker, 2008; van Harreveld, Rutjens, Schneider, Nohlen, & Keskinis, 2014, who similarly argue that these constructs are independent). As in prior attitude strength work, however, these variables are often treated as the same. For example, the construct of "self-concept clarity" is traditionally defined such that "confidence" and "consistency" of one's self-concept are one and the same (Campbell et al., 1996). Past research has also combined measures of ambivalence and certainty into composite indices (e.g., Kokkinaki, 1998; McGregor & Marigold, 2003; McGregor, Zanna, Holmes, & Spencer, 2001). Although these judgments may in fact be partially overlapping (i.e., subjective ambivalence may act as one input into an overall meta-cognitive judgment of certainty), we argue that ambivalence and certainty reflect distinct judgments despite surface-level similarities.

Consider people's attitudes toward their jobs. Even with unambivalent evaluations (e.g. uniformly negative), certainty can vary. For instance, people could feel uncertain of an unambivalent negative attitude (e.g., someone who has only had the job for one day and cannot yet be sure that he dislikes it) or they could feel certain of an unambivalent negative attitude (e.g., being sure that the attitude is only negative; no evaluative conflict). Similarly, with an ambivalent attitude (e.g., being conflicted over whether one likes or dislike the job), it is possible to hold this attitude with uncertainty (e.g., not knowing whether the positive or negative aspects of a job are more valid) or certainty (e.g., fully understanding the benefits and drawbacks of the job, therefore sure of a set of evaluative associations). Thus, although often related, these concepts can be conceptually separated.

In empirical support of this separability, many experimental manipulations of attitude certainty fail to affect ambivalence (e.g., Barden & Petty, 2008; Clarkson, Tormala, & Rucker, 2008; Dubois, Rucker, & Tormala, 2011; Petrocelli, Tormala, & Rucker, 2007), and other studies have shown effects of certainty on various attitude-relevant outcomes, either controlling for or in the absence of ambivalence effects (e.g., Alvarez & Brehm, 1997; Bassili, 1996; Craig, Martinez,

& Kane, 2005; McGraw, Hasecke, & Conger, 2003; Petrocelli et al., 2007). Still other research has documented interactions between certainty and ambivalence on important outcomes like temporal stability and resistance to persuasion (Clarkson et al., 2008; Luttrell, Petty, & Briñol, in press). Once again, however, we do not suggest that these variables are completely unrelated to one another. Indeed, several studies show how they are related in interesting ways (e.g., DeMarree, Briñol, & Petty, 2015; Jonas, Diehl, & Bromer, 1997; van Harreveld, Rutjens, Rotteveeel, Nordgren, & van der Pligt, 2009). Instead, we argue only that they are at least partially separable metacognitive appraisals of attitudes.

Therefore, following from the proposition that ambivalence and certainty are independent meta-cognitive evaluations, we predict neural dissociation such that attitudinal ambivalence and certainty can be connected to unique neural regions. Thus, we now turn to the current literature in neuroscience to form predictions about the particular brain regions where we expect to find the unique correlates of these two meta-cognitive appraisals.

Neural Bases of Ambivalence and Certainty

Existing research on the neural bases of attitudes and evaluations has tended to focus simply on valence, identifying the orbitofrontal cortex (OFC) and the ventral striatum as regions that track positivity versus negativity of judgments. The OFC, for instance, has been linked to processing subjective value or pleasantness across a range of stimuli like scents, foods, and people (Anderson et al., 2003; Cunningham, Johnsen, & Waggoner, 2011; Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; Kringelbach & Rolls, 2004; Lewis, Critchley, Rotshtein, & Dolan, 2007; Padoa-Schioppa & Assad, 2008; Plassmann, O'Doherty, & Rangel, 2007). In addition, and consistent with existing evidence that links this area to reward and value processing (e.g., Delgado, 2007), the ventral striatum also plays a role in evaluative processes as shown in the domain of consumer products (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007) and free-choice cognitive dissonance paradigms (Izuma et al., 2010; Jarcho, Berkman, & Lieberman, 2011).

Although some work has moved beyond simple valence, examining neural correlates of attitude strength indicators such as evaluative extremity (e.g., Anderson et al., 2003; Berntson et al., 2011; Cunningham, Raye, & Johnson, 2004; Cunningham, Van Bavel, & Johnsen, 2008), attitude strength constructs remain largely unexplored in social neuroscience. We thus turn to the broader literature in cognitive neuroscience, including conflict monitoring, decision conflict, and memory to identify brain regions likely to track attitudinal ambivalence and certainty.

The defining feature of ambivalence is cognitive conflict (van Harreveld, Schneider, Nohlen, & van der Pligt, 2012), a construct present in other areas of cognitive neuroscience. A common neural marker of cognitive conflict is the anterior cingulate cortex (ACC), which has been previously linked to the experience of decision conflict (Pochon, Riis, Sanfey, Nystrom, & Cohen, 2008) and to general conflict monitoring processes (Carter & van Veen, 2007). Indeed, a host of research in the attitudinal ambivalence literature has characterized ambivalence as a process tightly linked to the conflict that arises when making dichotomous good/bad judgments (for reviews, see van Harreveld, Nohlen, & Schneider, 2015; van Harreveld, van der Pligt, & De Liver, 2009). Thus, given the common cognitive process underlying decision conflict for similarly valued alternatives and the experience of translating an ambivalent attitude into a single evaluative response, we predicted that evaluating an object as good or bad would similarly activate the ACC as a function of the attitude’s associated ambivalence. Some prior research already supports a relationship between ambivalent reactions and ACC activity as well as a host of brain areas, including the right inferior frontal cortex, OFC, ventromedial prefrontal cortex, frontopolar cortex, temporal parietal junction, and posterior cingulate cortex (PCC; Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003; Cunningham et al., 2004; Jung et al., 2008; Nohlen, van Harreveld, Rotteveel, Lelieveld, & Crone, 2014). Similarly, the ACC has also been linked to cognitive dissonance, another form of social cognitive conflict (Kitayama, Chua, Tompson, & Han, 2013; van Veen, Krug, Schooler, & Carter, 2009).

With respect to attitude certainty, however, it is unclear whether the same cognitive conflict that gives rise to experienced ambivalence also underlies an attitude's corresponding degree of certainty or whether these variables instead result from partially separable processes. The existing literature remains silent on this question; no work has yet examined attitude certainty's neural correlates. It thus remains important to understand both the neural correlates of this impactful attitude strength variable and whether its neural underpinnings are independent of those related to ambivalence. To form more specific predictions, we look to research on memory and decision-making, in which certainty is a similarly impactful construct (Fleming & Dolan, 2012). In this research, a person's memory or decision can be held or made with varying degrees of confidence, and such confidence tends to be associated with parietal regions, including the precuneus/PCC (for a review, see Luttrell, Briñol, Petty, Cunningham, & Díaz, 2013). Results of a recent meta-analysis offer statistical support for the reliable role of this region in the degree of confidence in memory and decision-making domains (White, Engen, Sørensen, Overgaard, & Shergill, 2014). These results also point to several other brain regions that track subjective confidence, including other areas in the central executive network, especially in the dorsolateral prefrontal cortex (dlPFC).

The Present Study

The present study takes the first step toward understanding the neural representation of strong and weak attitudes by specifically examining the neural correlates of attitudes held with ambivalence separate from those related to attitudes characterized by certainty. We expect to find neural dissociations between ambivalence and certainty during exposure to visually presented words. Drawing from previous research, we predict ambivalence to be uniquely associated with ACC activation and certainty to be uniquely associated with precuneus/PCC activation.

To examine the unique neural correlates of attitude ambivalence and certainty, we adapted the procedure used by Cunningham and colleagues (2003). During scanning, participants evaluated 120 attitude objects as either "good" or "bad." After the scan session, these participants indicated their separate positive and negative attitudes toward each stimulus, the extent to which they felt conflicted about each stimulus, and how certain they were of their attitudes toward each stimulus. Importantly, this paradigm allowed us to examine neural activations during the evaluation of words rather than during the process of making certainty or ambivalence ratings themselves. In this way, we can understand more about the experience of evaluation itself that relate to corresponding attitude strength.

Method

Participants. Twenty-five right-handed participants (11 Male) provided informed consent and were paid $30 for participating in the experiment. Data from five participants were excluded from analyses due to issues arising during scanning, resulting in a total sample of N = 20 (9 Male).

Stimuli. Participants evaluated 120 attitude objects, presented as text both in the scanner and in a post-scan questionnaire. Attitude objects were chosen such that they varied conceptually on evaluative valence, certainty, and ambivalence. These words also ranged from relatively more abstract (e.g., *consumerism*) to relatively more concrete (e.g., *cheesecake*). Taken together, these words constitute a set that allows for conclusions about evaluative processes in general (see Appendix A for a full list).

Task and procedure. During fMRI scanning, participants completed an evaluation task. While in the scanner, we presented participants with 120 words (e.g. "consumerism", "cheesecake") in a random order, and participants indicated (using a button box) whether they evaluated each word as "good" or "bad" by pressing the corresponding button (counter-balanced between participants) with their left hand. Each word was presented on the screen for two seconds each. Following each word was a fixation cross that appeared for a variable length (average ITI = 8 s). Trials were separated into two functional runs, each consisting of 60 attitude objects.

Following fMRI scanning, participants responded to the same 120 words again by completing a computerized questionnaire. This questionnaire measured participants' attitudes, certainty, and subjective ambivalence in response to each of the attitude objects presented during the scanning session. To assess attitudes, participants responded to two unipolar scale items that measured positive and negative evaluations separately ("To what extent do you have NEGATIVE thoughts or feelings about this?" and "To what extent do you have POSITIVE thoughts or feelings about this?", 7-point scales with 1 = "no [negative/positive] thoughts or feelings" and 7 = "maximum [negative/positive] thoughts or feelings"). To assess attitude certainty, the questionnaire asked, "How CERTAIN are you that your attitude toward this is correct?" (7-point scale with 1 = "very uncertain" and 7 = "very certain"). Finally, to assess subjective ambivalence, the questionnaire asked "To what extent do you feel CONFLICTED about this?” (7-point scale with 1 = “feel no conflict at all” and 7 = “feel maximum conflict”). Participants answered all attitude questions for a given word before moving on to the next word.

fMRI parameters. This study was conducted using a Siemens 3.0-Tesla Trio scanner. Functional images were acquired using a single-shot gradient echo-planar pulse sequence (echo time = 26 ms, repetition time = 2.2 s, in-plane resolution = 2.5 × 2.5 mm, slice thickness = 2.7 mm, field of view = 250 mm).

fMRI preprocessing and analysis. We prepared the data using FSL (University of Oxford, Oxford, United Kingdom). Data pre-processing was carried out using FEAT (FMRI Expert Analysis Tool) Version 6.00, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). The following pre-processing transformations were applied: motion correction using MCFLIRT (Jenkinson, Bannister, Brady, & Smith, 2002), non-brain removal using BET (Smith, 2002) , spatial smoothing using a Gaussian kernel of FWHM 5 mm, grand-mean intensity normalisation of the entire 4D dataset by a single multiplicative factor, and highpass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma = 70 s). Following this, registration to high-resolution structural and Montreal-Neurological Institute (MNI) standard space images was performed using FLIRT (Jenkinson et al., 2002; Jenkinson & Smith, 2001).

Imaging analyses. Finding distinct neural regions responding to certainty and ambivalence would provide evidence that these judgments at least partially rely on different neural processes. To model both of these parameters simultaneously, we conducted a multilevel model in which the Blood-oxygen-level dependent (BOLD) response to each attitude object was predicted from participants’ certainty and ambivalence ratings. To estimate brain activation for each attitude object, we obtained a beta-weight estimate for each individual word presented to participants using the individual modulation command in AFNI (-stim_times_IM; see Mumford, Turner, Ashby, & Poldrack, 2012; Stillman, Van Bavel, & Cunningham, 2015). This method yields a single beta-weight for each voxel for each trial for each participant (yielding 2400 total beta-weights per each voxel), with each beta-weight representing the degree of BOLD activation in response to that specific trial for that participant. Then, using mixed effects modeling (Baayen, Davidson, & Bates, 2008), we model these individual trial activations as a function of the corresponding certainty and ambivalence ratings participants provided in the post-scan session. More specifically, we ran, for each voxel in the brain, a variable intercepts mixed effects model (using the lme4 package in R, Bates, Maechler, Bolker, & Walker, 2015) predicting voxel activity as a function of certainty and subjective ambivalence (level 1 variables) nested within subjects (level 2 variable). This yielded a T-value for both certainty and ambivalence for each voxel in the brain, resulting in two separate T maps – one for each of our predictors of interest. Resulting maps were corrected for multiple comparisons ($p < .05$; determined using AlphaSim) using a cluster threshold of 25 voxels at $p < .001$.

This analysis technique has several advantages relative to traditional methods of analyzing data. First, by individually predicting each trial, as opposed to aggregating across many trials, it allows us to model variance between trials as opposed to ignoring differences between them. Second, while existing analysis software allows something similar to this approach through parametric modulation, the present analysis strategy allows more specific modeling of the within and between error variances. Finally, as these models explicitly model dependencies in the data (as opposed to aggregating across non-independent data), they confer greater power relative to other analyses (see Baayen, Davidson, & Bates, 2008; Judd, Westfall, & Kenny, 2012). Conceptually, the subjective ambivalence and certainty scores were regressed against the fMRI signal for each trial (120 of trials per subject) with each participant providing a replication. All participants were modeled simultaneously to estimate random effects, and model the fixed effects of certainty and ambivalence on fMRI data (resulting in approximately 117 degrees of freedom per subject).

We further conducted a number of R-to-Z transformation analyses that allow us to test whether activation in one region is significantly greater for one of our predictors (e.g., ambivalence) versus another (e.g., certainty). Using the equation given in Cohen and Cohen (1983), we took the beta maps and standard error maps from the above analyses and subjected them to the transform formula, resulting in a Z score for each voxel of the brain, which we then subjected to a correction threshold of 10 contiguous voxels significant at $p < .05$. This allowed us to identify regions in which one of our beta weights were significantly greater than the other.

Results

Behavioral Data

For the present study, we were primarily interested in certainty and subjective ambivalence (i.e., how conflicted participants felt towards the attitude objects in question). Certainty and subjective ambivalence scores were left in their raw form, each ranging from 1 to 7. Across objects and participants, $M_{\text{certainty}} = 5.71$, $SD = 1.48$ and $M_{\text{ambivalence}} = 2.13$, $SD = 1.53$. To investigate the relationship between word ratings, we conducted several multilevel models in which words were nested within subject. Replicating previous work (e.g., Petrocelli et al., 2007; Smith et al., 2008; Wright, Cullum, & Schwab, 2007), certainty and ambivalence were negatively correlated ($\gamma = -.62$, $SE = .02$, $t(2369.6) = -43.0$, $p < .001$; overall $r = -.66$, average participant $r = -.63$). Further, these indices were only very weakly related to the positivity or negativity of the attitude object in question (overall $rs < .21$, average $ps > .15$; see Table 1).

Imaging Data[1]

Ambivalence. To investigate whether any brain regions preferentially activate for ambivalence over and above the effects for certainty, we conducted the above multilevel model, which estimates the unique variance accounted for by both ambivalence and certainty, controlling for one another. We found several regions in which greater activity corresponded to significantly greater ambivalence ratings (see Table 2 for a complete list). Consistent with previous work, we found a large region of activation within the anterior medial wall associated with greater subjective ambivalence (peak activation: x = 10, y = 14, z = 66). Within this region, we found regions of anterior cingulate cortex (peak activations: x = -2, y = 32, z = 24, cluster size = 84, max T = 4.35; x = -4, y = 40, z = 8, cluster size = 26, max T = 3.83). Additional clusters of activation were found for dorsomedial prefrontal cortex (peak activation: x = -2, y = 56, z = 20; see Figure 1A) and the posterior cingulate cortex (peak activation: x = -6, y = -48, z = 26). To address the possibility that these regions may respond to certainty at levels not detectable with our cluster correction threshold, we interrogated each of these regions, which revealed no significant association with certainty (anterior medial wall: γ = .81, *SE* = 5.28, t(2104.2) = .15, p = .88; ACC: γ = 4.80, *SE* = 6.60, t(2354.3) = .73, p = .47; dlPFC: γ = 9.10, *SE* = 7.60, t(1701.3) = 1.20, p = .23; PCC: γ = 13.55, *SE* = 7.59, t(2315.6) = , p = .07), suggesting that these regions were uniquely associated with subjective ambivalence (see Figure 2). No regions were significantly negatively associated with ambivalence ratings.

[1]Although valence was not the focus of the present paper, we note that we replicate many previous findings on valence (e.g., Barta, McQuire, & Kable, 2013) when we predict activation from valence. Specifically, we find several clusters that were significantly associated with negative valence, such as the Insula/lateral Orbitofrontal Cortex in the left (x = -42, y = 18, z = 0, cluster size = 2063) and right (x = 44, y = 26, z = -16, cluster size = 282) hemisphere, as well as the dmPFC/ACC (x = 4, y = 26, z = 40, cluster size = 2891). We further replicate past work investigating reactions to positive stimuli, finding a single cluster in the ventral striatum (x = 4, y = 18, z = -12, cluster size = 17), although this was slightly below our cluster correction criteria of 25 contiguous voxels.

Certainty. In the previous analysis, we found several regions associated with ambivalence controlling for certainty. To address whether certainty preferentially activates distinct brain regions from ambivalence, we examined the effects of certainty on brain activation controlling for ambivalence. We found several regions positively associated with certainty (see Table 3). Consistent with past research on certainty, we found regions in the precuneus/posterior cingulate cortex (peak activations: $x = 6$, $y = -54$, $z = 65$ and $x = 4$, $y = -32$, $z = 48$, see Figure 1B) that were significantly associated with participants' certainty ratings. Importantly, these regions are non-overlapping with the posterior cingulate activations found for subjective ambivalence ($\gamma = 9.22$, $SE = 6.89$, $t(2243.5) = 1.34$, $p = .18$ and $\gamma = 10.66$, $SE = 8.42$, $t(2216.4) = 1.27$, $p = .21$ respectively, see Figure 3). Further, and consistent with previous work documenting a dorsal/ventral distinction in the posterior cingulate cortex (e.g., Leech, Braga, & Sharp, 2012; Vogt, Vogt, & Laureys, 2006), we found that certainty was related to activity in more dorsal regions of posterior cingulate cortex and precuneus, whereas ambivalence was related to activity in more ventral posterior cingulate cortex. As was the case with ambivalence, no regions were significantly negatively associated with certainty. Finally, because certainty and subjective ambivalence share 36% of their variance on average, we conducted several control analyses, which we report in the Supplementary Section.

Direct comparison of confidence and ambivalence. Thus far we have documented that certain regions respond preferentially to either certainty or ambivalence. However, these analyses do not directly compare the strength of effects for ambivalence and certainty. Thus, to provide further evidence that these regions are indeed more sensitive to one variable than another, we conducted an R-to-Z transform analysis. For each voxel identified above as significantly responding to either ambivalence or certainty, the R-to-Z transform identified whether that voxel activated significantly greater to one relative to the other. We then subjected these maps to the cluster correction criteria of 10 contiguous voxels significant at $p < .05$. This yielded two regions in which activation was significantly stronger to ambivalence relative to certainty – the paracingulate gyrus and the inferior frontal gyrus (see Table 4) – and five regions in which activation was significantly stronger to certainty relative to ambivalence – including the more dorsal precuneus cluster discussed above (see Table 5). Taken together, these results further suggest different regions underlie the different meta-cognitive attitude strength indicators of certainty and ambivalence.

Overlap. In the previous analyses, we demonstrated some degree of processing independence for subjective ambivalence and certainty. Yet, finding evidence for dissociation does not imply complete processing independence. Indeed, it is possible that these two components consist of both shared and distinct processes. To test for shared neural processes of the meta-cognitive processing of evaluative attitudes, we performed a conjunction analysis to determine regions that were significantly associated with both subjective ambivalence and certainty. This analysis indicated that a single region of right dorsolateral prefrontal cortex was associated with both forms of meta-cognition, controlling for each other ($x = 48$, $y = 26$, $z = 24$, see Figure 1C and Figure 4).

Discussion

Attitudes researchers have long highlighted that, in addition to the valence of our attitudes, the strength with which we hold these evaluations is critical. The present research sought to both understand the neural processes underlying attitude strength, as well as address a debate in the literature by testing whether certainty and ambivalence represent distinct underlying neural processes. Supporting the hypothesis that certainty and ambivalence are distinct, we found that while certainty was largely associated with relative increases in precuneus and dorsal PCC activation during evaluation, ambivalence was associated with increased activation in the ACC, medial prefrontal cortex, and ventral PCC. Although certainty and ambivalence are unquestionably related, that different regions are uniquely responsive to each construct suggests that the two are indeed separable.

These findings replicate and extend existing neuroimaging research on the role of the ACC in other cognitive processes in which “conflict” plays a consequential role (Carter & van Veen, 2007; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Pochon et al., 2008). The present research suggests that in addition to conflicting emotions, decisions, and outcomes, the ACC is recruited for evaluations of attitude objects about which people feel mixed or conflicted. It is important to note that we do not intend to suggest that these data argue for ambivalence as a particularly unique form of cognitive conflict. Instead, we view these results as an instance of neural commonality across phenomena from different fields of research in psychology that otherwise resemble one another at the process level.

Nevertheless, our data cannot explicitly clarify whether the neural activation corresponding to attitude ambivalence is the same as or distinct from similar findings related to decision conflict. That is, the results we have obtained may be due entirely to the relative difficulty of making dichotomous “good” vs. “bad” responses for stimuli about which a person has a more ambivalent attitude, rather than stemming from attitudinal ambivalence per se. We invite future research to clarify this point, perhaps by implementing tasks that encourage people to attend to stimuli without having to render a discrete judgment. In so doing, the task will encourage ambivalence-related neural processes without invoking additional decision-related processes. In the same vein, we regret that reaction time measures were not recorded in this study and recommend that future neuroimaging research on attitude strength variables records the time it takes for people to make evaluative judgments. Indeed, reaction times are a common measure in attitude strength research (see Fazio, 1995) as well as related fields like decision science (see Pleskac & Busemeyer, 2010). Accounting for this common measure could provide a more nuanced understanding of the neural distinctiveness and overlap between attitudes and other psychological processes.

These results also add to our understanding of the role of the precuneus in evaluations. Adding to existing evidence linking precuneus activity to memory and choice confidence (Luttrell et al., 2013; White et al., 2014), the present work shows that certainty in evaluations more generally is also associated with heightened precuneus activation. As with the results for ambivalence, we view these data as support for common neural processes associated with metacognitive confidence across choice, memory, and evaluative contexts. These results demonstrate how theoretical questions in one area of psychology (attitudes) can be addressed using neuroscience methods, drawing on established findings in distinct fields of research that nonetheless speak to core cognitive processes.

These results also point to convergence between the two indicators of attitude strength: both certainty and ambivalence uniquely activated regions within the PCC. This may be related to this region’s functionality as an integrator of information across the neural network, indicated by its high connectivity to disparate areas of the brain (Leech et al., 2012). It is possible, then, that the increased activation in response to certainty and ambivalence results from increased metabolic demands required for integration across multiple competing inputs.

Although both ambivalence and certainty corresponded to similar regions in the parietal cortex, there were clear spatial distinctions; ambivalence corresponded to ventral PCC (vPCC) activation whereas certainty corresponded to precuneus and dorsal PCC (dPCC) activation. Although these regions are generally considered highly interrelated and homogenous, our results add to a growing body of research documenting their heterogeneity. For instance, the ACC is more tightly connected to the vPCC than dPCC (Vogt & Pandya, 1987; Vogt et al., 2006), consistent with our findings that ambivalence activated both ACC and vPCC. Furthermore, Leech, Braga, and Sharp (2012; see also Leech, Kamourieh, Breckmann, & Sharp, 2011; Vogt et al., 2006) recently documented that default mode processing relates especially to vPCC regions, whereas executive functioning relates especially to dPCC regions. The similar dissociation we found between ambivalence and certainty suggests that these attitude strength variables may differ in these corresponding neural computations (e.g., ambivalence judgments may relate more to self-referential thought, a process implicated in default mode processing, and certainty judgments may relate more to cognitive control processes). We invite future research to investigate these possibilities.

We further found evidence of shared neural processing for certainty and ambivalence in the dorsolateral prefrontal cortex. This region responded significantly to words associated with both increasing certainty and ambivalence (controlling for one another), suggesting that it is used under conditions of both certainty and ambivalence. Thus, despite a neural distinction between certainty and ambivalence, there is also some degree of neural overlap for these two unique attitude strength indicators.

These data may also suggest a novel conceptualization of attitude strength overall, drawing on related models that identify different levels of valence. These models distinguish between “micro” and “macro” valence, noting that at the micro level, various appraisals of a stimulus may evoke a range of independent positive and/or negative evaluations, but at the macro level, these potentially competing micro-valences are integrated into a summary unidimensional evaluation that helps guide choice and behavior (Shuman, Sander, & Scherer, 2013). Similarly, individual indicators of attitude strength may function independently at a micro level but in an integrated fashion at a macro level as a means to consolidate the overall strength of the attitude. Our data support a neural account for such a model; we found neural dissociation for both certainty and ambivalence – two indicators of attitude strength – and we also found that these variables independently indicated the dorsomedial prefrontal cortex. Given the role of dorsolateral PFC in working memory (e.g., Curtis & D'Esposito, 2003), and particularly in the integration of complex information (e.g., Kroger et al., 2002), the present data suggest a possible unified attitude strength indicator that consists of integrating across distinct elements. This account also offers one reason why various attitude strength indicators reflect unique processes despite converging to predict a set of common attitude outcomes (Visser et al., 2006).

Conclusion

The way we evaluate and process information underlies all facets of social life. Our evaluations, however, are often more nuanced and complex than simple judgments of "good" or "bad." In the present paper, we propose that neuroscientists interested in the evaluative process must consider these additional attitude strength properties in addition to an attitude's valence. These properties, however, are not redundant with one another; different neural processes appear to underlie the strength variables of certainty and ambivalence, suggesting they represent distinct, although related, assessments of one's evaluation. By using neuroimaging methods to probe questions raised by the attitude strength literature, the present study both provides insight into the neural representation of attitudes and evaluative processes and also informs the social psychological approach to attitudes and their corresponding meta-cognitive appraisals.

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	Positive	Negative	Ambivalent
Positive			
Negative	-.78***		
Ambivalent	-.04	.21	
Certain	.06	-.06	-.66*

Table 1. Average correlations between positive, negative, ambivalence, and certainty ratings.
***: average $p < .001$; *: average $p < .05$

Region	Cluster size	X	Y	Z	Peak activation (T score)
Anterior Medial Wall	1137	10	14	66	5
	29	39	76	49	3.93
Frontal operculum cortex	927	-44	18	-2	5.59
Dorsolmedial PFC	419	-2	56	20	5.38
Lingual cortex	144	14	-78	-2	4.29
	108	-10	-74	2	4.27
Frontal pole	117	-8	54	40	4.69
	43	24	80	49	4.27
Middle frontal gyrus	105	-48	6	52	4.25
	67	-38	32	42	4.44
Orbitofrontal cortex	100	-48	38	-12	4.42
Angular gyrus	91	-50	-56	44	4.26
Posterior cingulate cortex	67	-6	-48	26	3.98
Lateral occipital cortex	41	71	31	53	4.23
Inferior frontal gyrus	25	19	75	35	3.61

Table 2. List of clusters surviving cluster correction for ambivalence. All regions are positively correlated with ambivalence. Coordinates listed in MNI space.

Region	Cluster size	X	Y	Z	Peak activation (T score)
Angular gyrus	302	60	-48	32	4.44
Planum temporale	165	-62	-22	10	4.56
	47	-50	-40	20	4.14
Supramarginal gyrus	128	-52	-46	52	4.11
	105	66	-32	32	4.19
Frontal pole	61	40	34	24	3.88
Precentral gyrus	51	42	6	26	4.86
Middle frontal gyrus	47	38	2	64	4.19
Precuneus	42	4	-32	48	4.08
	40	6	-54	58	3.98
Central opercular cortex	28	58	-12	8	3.71

Table 3. List of clusters surviving cluster correction for certainty. All regions are negatively correlated with ambivalence. Coordinates listed in MNI space.

Region	Voxels	X	Y	Z	Peak Activation (Z score)
Frontal Operculum Cortex	211	-44	18	-12	4.77
Dorsal-medial prefrontal cortex	126	6	26	34	4.34

Table 4. List of clusters surviving correction in which the strength of ambivalence was significantly greater than the strength of certainty, as indicated by an R-to-Z analysis.

Region	Voxels	X	Y	Z	Peak Activation (Z score)
Planum Temporale	45	-62	-22	6	2.48
Supramarginal Gyrus, anterior division	40	66	-28	30	2.81
Supramarginal Gyrus, posterior division	16	42	-44	44	2.36
Superior Temporal Gyrus, posterior division	15	64	-14	2	2.36
Precuneus	13	6	-32	46	2.66

Table 5. List of clusters surviving correction in which the strength of ambivalence was significantly greater than the strength of certainty, as indicated by an R-to-Z analysis.

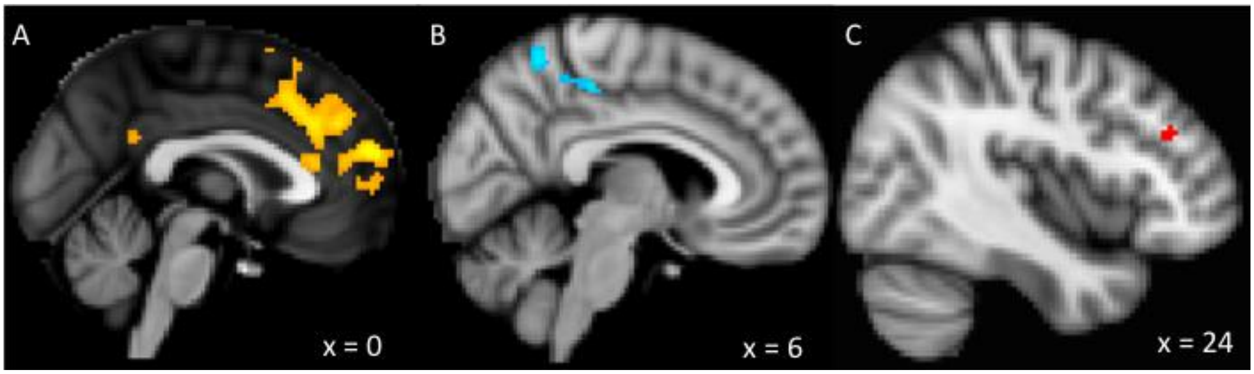

Figure 1. Activation map for regions significantly positively related to (A) ambivalence, (B) certainty, or (C) both. All significance maps are calculated controlling for the other variable (i.e., ambivalence controlling for certainty and vice-versa).

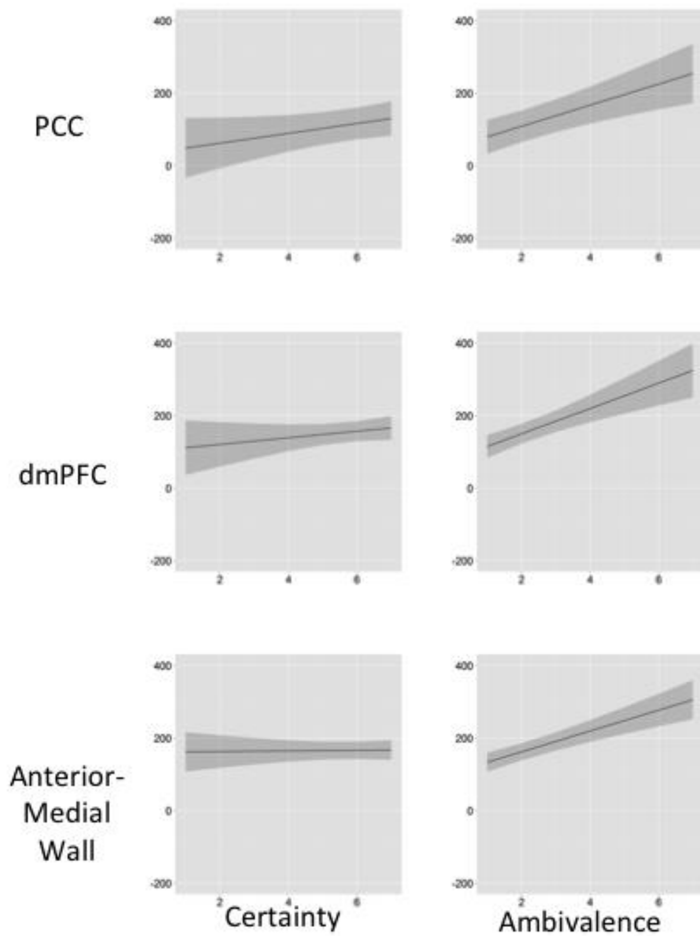

Figure 2. Estimated BOLD response to both certainty and ambivalence for clusters identified as being significantly responsive to ambivalence ratings. Each region shown was significantly related to ambivalence ratings, but none were significantly related to certainty ratings (the relationship between certainty and activity in the PCC cluster was marginal, $p = .07$). Units are BOLD activation.

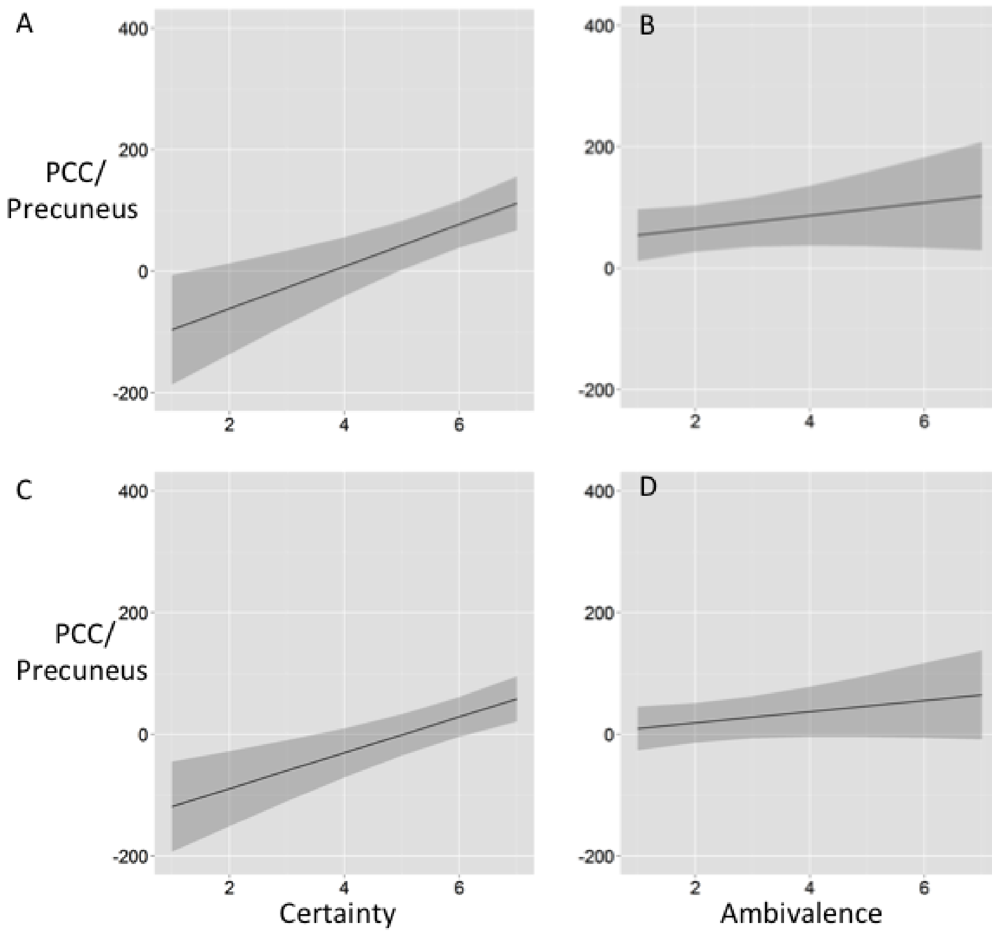

Figure 3. Estimated BOLD response to both certainty and ambivalence for clusters identified ad being significantly responsive to certainty ratings within the precuneus and PCC (top: x = 6, y = -54, z = 65; bottom: x = 4, y = -32, z = 48). Both regions were significantly related to certainty ratings, but neither was significantly related to ambivalence ratings. Units are BOLD activation.

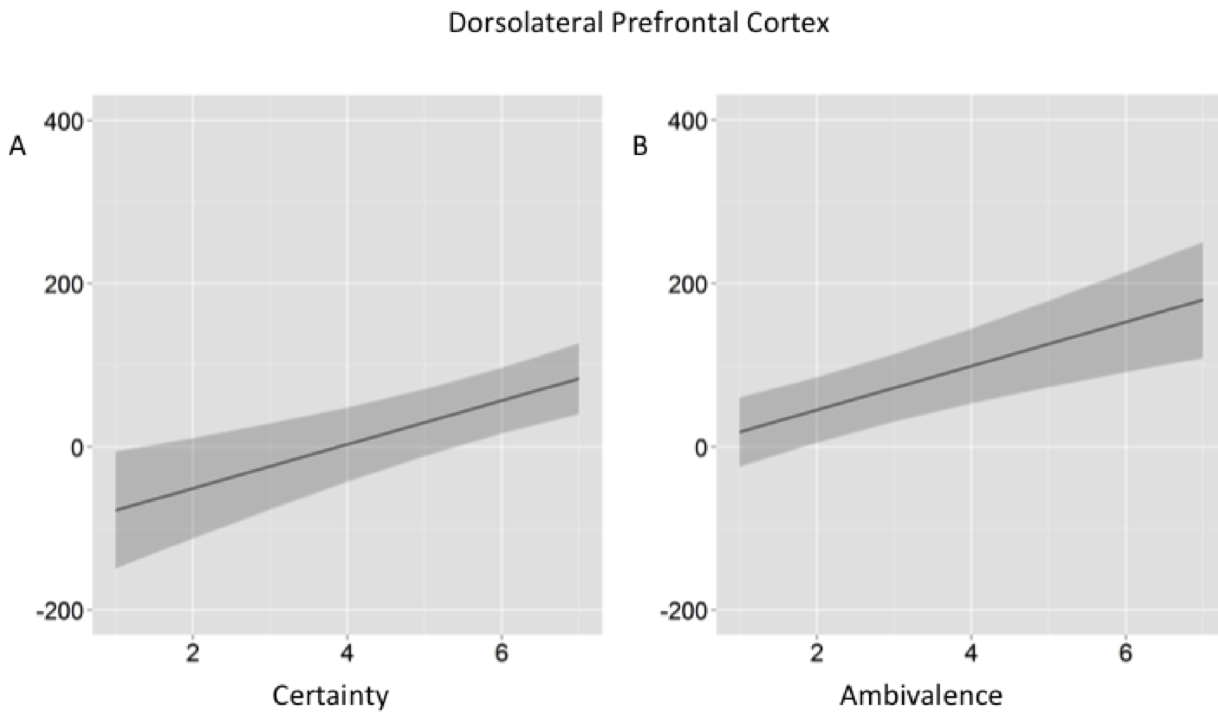

Figure 4. Estimated BOLD response to both certainty and ambivalence in the dorsolateral cluster that significantly responded to both certainty and ambivalence (*x* = 48, *y* = 26, *z* = 24). Both ambivalence and certainty (controlling for one another) were significantly positively related to neural activity in this cluster. Units are BOLD activation.

Appendix A

Words Used as Topics of Evaluation

Below, we present the mean subjective ambivalence and certainty ratings for each topic used in this study. Standard deviations are presented in parentheses.

Topic	Subjective Ambivalence	Certainty
ABUSE	1.20 (1.00)	6.76 (0.52)
ALARM CLOCKS	2.84 (1.75)	5.16 (1.49)
ALCOHOL	2.84 (1.93)	5.44 (1.47)
BABIES	2.36 (1.66)	5.52 (1.64)
BEACHES	1.84 (1.28)	5.92 (1.22)
BEEF	2.48 (1.53)	5.72 (1.14)
BICYCLES	1.40 (0.71)	6.36 (0.95)
BIOLOGICAL WEAPONS	1.84 (1.31)	5.80 (1.55)
BIRDS	1.56 (1.16)	5.92 (1.22)
BITTERNESS	1.76 (1.05)	5.84 (1.18)
BLACK AMERICANS	2.44 (2.00)	5.40 (1.80)
BLISTERS	1.28 (0.68)	6.28 (1.02)
BOOKS	1.56 (1.00)	6.20 (1.12)
BREAKFAST	1.36 (0.91)	6.36 (1.08)
CANADA	1.32 (0.75)	5.68 (1.57)
CANDLES	1.80 (1.32)	6.24 (0.93)
CANDY	2.40 (1.47)	5.20 (1.50)
CATS	1.68 (1.03)	5.88 (1.27)
CELL PHONES	2.80 (1.47)	5.24 (1.20)
CHEESECAKE	1.96 (1.17)	6.08 (1.08)
CHINA	3.20 (1.47)	4.24 (1.74)
CHOCOLATE	1.84 (1.18)	5.92 (1.41)
CHRISTIANS	3.04 (1.72)	5.28 (1.70)
COCAINE	1.68 (1.22)	6.16 (1.07)
COFFEE	1.48 (1.00)	6.28 (1.06)
COLLEGE	2.20 (1.58)	6.00 (1.15)
COMEDY	1.28 (0.68)	6.60 (0.71)
COMPASSION	1.44 (0.87)	6.44 (1.00)
CONSUMERISM	2.84 (1.46)	4.76 (1.56)
COOKING	1.32 (0.75)	6.28 (1.21)
CREATIVITY	1.32 (0.80)	6.24 (1.09)
CRIMINALS	2.04 (1.67)	6.20 (1.19)

Topic	Subjective Ambivalence	Certainty
DANCING	1.52 (1.08)	6.08 (1.22)
DEATH	2.44 (1.64)	5.92 (1.26)
DEATH PENALTY	3.84 (2.08)	4.88 (1.59)
DEFORESTATION	1.72 (1.14)	6.04 (1.21)
DEMOCRATS	2.60 (1.26)	5.12 (1.20)
DENTIST	2.12 (1.51)	5.68 (1.31)
DIRT	1.68 (1.03)	5.40 (1.53)
DISEASE	1.96 (1.24)	6.16 (0.80)
EXAMS	2.48 (1.45)	5.32 (1.49)
FARMS	2.64 (1.70)	5.76 (1.01)
FLOWERS	1.56 (1.12)	6.12 (1.17)
FOX NEWS	1.64 (1.15)	5.60 (1.89)
FRATERNITY	2.60 (1.83)	5.04 (2.05)
FRIENDS	1.80 (1.55)	6.44 (0.92)
FRUIT	1.04 (0.20)	6.52 (1.08)
GAMBLING	2.52 (1.42)	5.36 (1.44)
GARBAGE	1.44 (0.82)	6.12 (1.20)
GEORGE WASHINGTON	1.92 (1.15)	5.04 (1.67)
GIFTS	1.52 (0.92)	5.96 (1.31)
GUNS	2.64 (1.58)	5.36 (1.52)
HAWAII	1.40 (0.82)	5.96 (1.49)
HIKING	1.48 (0.87)	6.20 (0.96)
HOLIDAYS	1.56 (1.26)	6.28 (1.24)
HOMELESSNESS	1.72 (1.24)	6.52 (0.92)
HOMOSEXUALS	1.76 (1.59)	6.08 (1.47)
HOSPITAL	2.40 (1.50)	5.36 (1.32)
HOT SAUCE	1.48 (0.92)	6.00 (1.32)
ICE CREAM	1.76 (1.39)	5.64 (1.50)
INJECTIONS	2.48 (1.42)	5.52 (1.39)
KNITTING	1.76 (1.30)	5.36 (1.41)
LANDLORDS	2.63 (1.44)	4.44 (1.78)
LARGE CORPORATIONS	2.96 (1.88)	4.72 (1.84)

Topic	Subjective Ambivalence	Certainty
LIBRARIES	1.56 (1.00)	6.08 (1.08)
LOVE	2.36 (1.91)	6.20 (1.29)
MARIJUANA	2.84 (2.12)	4.84 (2.25)
MCDONALDS	2.32 (1.52)	5.88 (1.36)
MICROSOFT	2.88 (1.39)	4.28 (1.46)
MONEY	3.44 (2.00)	5.12 (1.74)
MOVIES	1.64 (1.08)	6.08 (0.86)
MURDER	1.40 (1.26)	6.88 (0.33)
MUSIC	1.24 (0.52)	6.72 (0.46)
NEWSPAPERS	2.16 (1.34)	5.36 (1.19)
NPR	1.60 (1.12)	5.40 (1.78)
NUCLEAR POWER	3.40 (1.47)	5.04 (1.37)
OBESITY	1.68 (1.11)	6.48 (0.82)
OHIO STATE		
UNIVERSITY	2.12 (1.36)	6.00 (1.15)
ORGANIC FOOD	2.32 (1.44)	5.48 (1.42)
PARTYING	2.72 (1.51)	5.36 (1.41)
PINEAPPLES	1.28 (0.89)	6.36 (0.99)
PLASTIC	3.04 (1.72)	4.36 (1.50)
POLICE	3.00 (1.50)	5.04 (1.46)
POLLUTION	1.36 (0.99)	6.28 (1.43)
POVERTY	1.68 (1.46)	6.60 (0.65)
PRIEST	2.76 (1.54)	4.92 (1.71)
PUBLIC SPEAKING	2.40 (1.89)	5.44 (1.29)
PUPPIES	1.36 (0.76)	6.16 (1.18)
RADIATION	2.72 (1.62)	5.24 (1.45)
RAIN	1.68 (1.11)	6.08 (1.00)
RAPE	1.24 (1.20)	6.84 (0.37)
RATS	1.84 (1.14)	5.60 (1.61)
RATTLESNAKE	2.20 (1.63)	5.16 (1.75)

Topic	Subjective Ambivalence	Certainty
REALITY TV	1.96 (1.34)	5.48 (1.45)
RECYCLING	1.48 (0.82)	6.48 (0.96)
REPUBLICANS	3.04 (1.77)	5.04 (1.65)
SAME-SEX		
MARRIAGE	1.72 (1.40)	6.48 (0.82)
SHARKS	2.36 (1.41)	5.20 (1.58)
SLEEP	1.32 (0.95)	6.48 (1.05)
SMOKING	2.08 (1.89)	6.46 (1.06)
SNOW	1.96 (1.21)	5.84 (1.03)
SPACE		
EXPLORATION	1.72 (1.21)	5.72 (1.51)
SUICIDE	2.20 (1.89)	5.76 (1.90)
SUNSHINE	1.50 (1.02)	6.36 (1.08)
SWIMMING	1.64 (0.99)	5.96 (1.10)
TAXES	3.36 (1.78)	4.96 (1.77)
TEENAGERS	2.48 (1.19)	5.24 (1.56)
TELEVISION	2.80 (1.35)	5.20 (1.19)
THERAPY	2.96 (1.74)	5.20 (1.32)
THUNDERSTORMS	1.72 (1.43)	6.08 (1.32)
TOFU	1.84 (1.28)	5.56 (1.12)
TRANSPORTATION	1.56 (0.96)	5.68 (1.35)
TRUST	2.36 (1.89)	6.04 (1.46)
TUITION INCREASE	2.00 (1.22)	6.04 (1.21)
UNITED STATES	2.56 (1.61)	5.64 (1.38)
VEGANS	2.28 (1.28)	5.20 (1.66)
VIOLENCE	2.08 (1.35)	6.00 (1.32)
WAL-MART	2.64 (1.58)	5.68 (1.49)
WAR	2.60 (1.73)	5.72 (1.37)
WEALTHY	2.92 (1.50)	5.00 (1.29)