

The embodiment of emotion: language use during the feeling of social emotions predicts cortical somatosensory activity

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Complex social emotions involve both abstract cognitions and bodily sensations, and individuals may differ on their relative reliance on these. We hypothesized that individuals' descriptions of their feelings during a semi-structured emotion induction interview would reveal two distinct psychological styles—a more abstract, cognitive style and a more body-based, affective style—and that these would be associated with somatosensory neural activity. We examined 28 participants' open-ended verbal responses to admiration- and compassion-provoking narratives in an interview and BOLD activity to the same narratives during subsequent functional magnetic resonance imaging scanning. Consistent with hypotheses, individuals' affective and cognitive word use were stable across emotion conditions, negatively correlated and unrelated to reported emotion strength in the scanner. Greater use of affective relative to cognitive words predicted more activation in SI, SII, middle anterior cingulate cortex and insula during emotion trials. The results suggest that individuals' verbal descriptions of their feelings reflect differential recruitment of neural regions supporting physical body awareness. Although somatosensation has long been recognized as an important component of emotion processing, these results offer 'proof of concept' that individual differences in open-ended speech reflect different processing styles at the neurobiological level. This study also demonstrates SI involvement during social emotional experience.

Keywords: emotion; somatosensory; language; fMRI

Emotions involve physiological changes in the brain and body that organize cognition and can sometimes be felt (Damasio, 1994/2005; Barrett et al., 2007). Thus, emotional feelings are driven not only by situational knowledge and cognitive assessments but also by input from bodily reactions (Damasio, 1999; Craig, 2002; Harrison et al., 2010; Herbert and Pollatos, 2012). These physical sensations underscore the fundamental interdependence between body and mind, maintained even in psychologically complex emotional states. Neurobiologically, complex social emotions such as sympathy (Decety and Chaminade, 2003), moral indignation (Moll, et al., 2005), admiration and compassion (Immordino-Yang et al., 2009) have been found to recruit cortical and subcortical structures involved in sensing and regulating internal organism states, such as the insula and dorsal anterior middle cingulate cortex.

The relative contributions of body sensations and cognitive deliberations to emotional experiences can vary not only by situation but also by individual—different people may rely more or less on cues from the physical body in processing emotionally evocative information. Variation in interoceptive ability, or somatosensory awareness for the internal body, has been associated with variation in individuals' expressed emotionality (Pollatos et al., 2005), trait measures of affective experience (Critchley et al., 2004), feelings of arousal in verbal reports of experienced emotion (Barrett, et al., 2004) and strength of non-conscious fear priming (Katkin et al., 2001). Areas of the brain underlying somatosensory and interoceptive processing have also been implicated in individual differences in traits relevant to social emotions, such as empathy. For example, self-report measures of empathy have been associated with neural activation in the anterior insula and

anterior middle cingulate during tasks involving social pain (Eisenberger et al., 2003) and empathy for another's pain (Singer et al., 2004; Masten et al., 2011).

Researchers have distinguished at both the behavioral and neural levels between 'bottom-up' emotion generation—that is, emotions that originate from visceral and autonomic responses—and 'top-down' emotions that result from cognitive processes such as appraisal (e.g. Ochsner et al., 2009). However, these studies have generally not focused on individual differences and in fact have actively minimized inter-individual variability, e.g. by instructing participants in how to reappraise stimuli (e.g. Ochsner et al., 2009; McRae et al., 2012). Nonetheless, a small body of research has identified that variability in both top-down and bottom-up processes across individuals exists (e.g. Hamann and Canli, 2004; Ray et al., 2005), suggesting that some people may spontaneously rely more on body sensation when formulating emotional feelings, while others may take a more abstract or intellectualized approach. These differing emotion processing styles may manifest themselves in language: for example, metaphors often include 'embodied' or visceral language (e.g. to grasp an idea or to feel hot with passion) that have been suggested to rely on sensorimotor simulation (Gallese and Lakoff, 2005).

Therefore, although predominant theories of emotion ascribe an important role to somatosensory processing in the generation of subjective feeling states, we sought to test whether individuals would show systematic differences in real-time, open-ended verbal descriptions of their emotional feelings and whether such differences would correspond to differential recruitment of somatosensory processing in the brain during the experience of complex social emotions. In assessing individuals' emotional processing styles in their spontaneous speech, we focused specifically on affective language, i.e. words referencing emotional valence, labels and feeling states. We then examined individual differences in affective word use relative to the use of cognitive words that referenced mental states and abstract or cognitive processes. We expected that individuals who used more affectively charged

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language to describe their feelings would show more somatosensory activation during emotion processing, relative to individuals who described their feelings in more cognitive, thought-based terms. This is the first study, to our knowledge, to combine quantitative analysis of open-ended speech with blood oxygen level dependent (BOLD) functional magnetic resonance imaging (fMRI) data.

In this study, quantitative linguistic analysis was applied to transcripts of participants talking about their emotional responses to a series of narratives, and then language use was correlated with participants' subsequent neural responses to the same narratives. The target emotions were admiration and compassion, two complex social emotions that have been shown to strongly recruit somatosensory and self-related neural processing (Immordino-Yang et al., 2009).

NEURAL BASES OF ADMIRATION AND COMPASSION

This study uses an emotion induction method developed for an earlier study of social emotions (Immordino-Yang et al., 2009), in which brief narratives describing real people's experiences were used to induce varieties of either admiration or compassion in an interview and then again during fMRI scanning. Narratives were designed to elicit compassion for physical or for social pain, or admiration for skill or for virtue. A control condition included social narratives without strong emotional content (beyond being interesting). The four emotion conditions were found to recruit cortical and subcortical regions associated with interoceptive representation and homeostatic regulation (e.g. anterior insula, anterior cingulate, hypothalamus and mesencephalon) relative to control (Immordino-Yang et al., 2009).

This study uses a new sample and explores whether individuals' emotional language is linked with neural activations during emotion processing in regions of the brain that sense the body. We examine participants' use of affective words relative to cognitive words while verbally describing their emotional responses to the narratives, and correlate individual differences in word use with differences in BOLD.

QUANTITATIVE ANALYSIS OF NATURAL LANGUAGE USING LIWC

Quantitative analysis of natural language has been used in a variety of studies to explore individual differences in speech and writing. This study uses the text analysis program Linguistic Inquiry and Word Count (LIWC; Pennebaker et al., 2007), which contains a dictionary of over 2000 words in 70 language categories and counts the frequency of words in each category. LIWC has been used to examine many different kinds of written and oral language samples, from expressive writing to diaries to course assignments to marital interactions (Pennebaker and Francis, 1996; Sillars et al., 1997; Pennebaker and King, 1999). LIWC analyses have found evidence of individual differences in 'linguistic style' that appear stable within individuals across time and topic. Even spontaneous word use in everyday conversation exhibits within-person consistency over time (Mehl and Pennebaker, 2003). LIWC word counts have been correlated with personality, projective measures and observed behavior (Pennebaker and King, 1999; Tausczik and Pennebaker, 2010).

This study focused on the 'cognitive words' and 'affect words' categories, situating each participant in terms of his or her relative use of the words in each category as a proportion of total words spoken. The 'cognitive words' category includes 730 words such as 'think', 'know', 'assume', 'should' and 'acknowledge'—that is, words reflecting mental states and abstract thinking. Cognitive word use appears to vary by both personality and situational factors. For example, in an analysis of 2004 presidential campaign speeches, Dick Cheney and John Kerry used more cognitive words than George Bush or John Edwards (Slatcher et al., 2007); in Beatles lyrics, John Lennon used more cognitive words than Paul McCartney (Petrie et al., 2008). Cognitive word

use may increase during crises, perhaps reflecting attempts to make sense of an event through strategies such as distancing or reappraisal. Rudy Giuliani's speeches included more cognitive words during difficult times (like during the dissolution of his marriage and after the September 11 attacks; Pennebaker and Lay, 2002) and cognitive words have been found to increase during and after relationship break-ups (Boals and Klein, 2005) and after disasters (Gortner and Pennebaker, 2003). This study aimed to hold situational factors constant throughout the interview so that individual differences in speech style could emerge for later correlation with BOLD data.

The other category of interest was 'affect' words, including 915 words reflecting both positive and negative emotions such as 'happy', 'inspiring', 'crying', 'abandon' and 'cruel'. Use of affect words has been associated with personality test measures such as the Five-Factor Inventory (Lee et al., 2007). Fiction writers use more affect words in interviews than physicists (Djikic et al., 2006). Rates of affect words typically increase over baseline during expressive writing and emotional disclosure exercises (e.g. D'Souza et al., 2008). Since our protocol involves emotional disclosure, we expected that it would elicit affect word use among our participants, but to varying degrees depending on individual differences.

This study investigated whether participants showed individual differences in the words they used to describe complex social emotions. We expected that cognitive word use would reflect a more abstract, deliberative emotional style and that affect words would reflect more embodied, physical engagement with emotion, and that these styles would correlate with patterns of neural activity during narratives designed to elicit feelings of admiration and compassion, but not control narratives.

HYPOTHESES

This study has two parts: first, we explored whether the cognitive and affect words participants used to describe their feelings showed consistent individual differences, and we examined the relationships between these categories of word use. We hypothesized that the word use categories would show intra-individual stability across the variety of emotions induced during the interview and that they would be negatively correlated with each other.

Next, we probed the correspondence of these categories to BOLD activity. We hypothesized that people who used more affect words relative to cognitive words would show higher BOLD activity in areas of the brain associated with bodily sensation, including the somatosensory cortices, insula and anterior cingulate cortex (ACC). We expected that these results would reflect a genuine difference in processing style rather than an overall increase in emotionality; as such, we expected word use to be uncorrelated with button-press ratings of emotion strength collected during fMRI scanning. We also expected that these results would reflect a difference specific to emotion processing, and as such that the associations with BOLD would not hold during relatively unemotional control social processing.

METHODS

Participants

Twenty-eight right-handed, healthy, native English-speaking participants (16 females and 12 males) were recruited for the study. Participants were all students or staff at a large private university on the US West Coast. The average age was 21.29 years (range: 18–27 years, *s.d.* = 2.65). Fourteen participants were identified as Caucasian-American, 12 as Asian-American, 1 as Latino-American and 1 as African-American.

Procedures

Before entering the scanner, participants took part in a two-hour one-on-one interview with an experimenter, following the method described in Immordino-Yang et al. (2009). The experimenter presented 50 true narratives depicting real people (not actors or celebrities) using a scripted verbal description supplemented by video and audio clips shown on a laptop. Fifty narratives (10 per condition), each taking 60–90 s to recount, were presented to elicit (i) admiration for virtue (narratives involved demonstrations of marked self-sacrifice and dedication to helping others); (ii) admiration for skill (narratives involved demonstrations of exceptional talents in athletics, the arts or other domains); (iii) compassion for social pain (narratives involved situations of bereavement, social rejection and other forms of psychological pain); (iv) compassion for physical pain (narratives depicted accidental bodily injuries, e.g. sports accidents) and (v) control social processing (narratives involved interesting situations with real people, such as a man describing his adventures abroad, that were not as emotionally evocative as narratives in the other categories). Length and use of video *vs* audio stimuli did not differ systematically between conditions. After each narrative presentation, participants were asked ‘How does this person’s story make you feel?’ as an open-ended prompt to describe their emotional responses. Participants were not told the emotion categories in the experiment and were encouraged to be as honest and open as possible. These interviews were videotaped and transcribed, and transcriptions were independently verified.

Following the interview, participants entered the MRI scanner, where they watched 5 s ‘reminder’ video clips excerpted from each of the narratives presented in the interview, followed by 13 s of gray screen and 2 s of fixation. During each scanning trial, participants rated the strength of their real-time emotional responses to the narrative stimulus using a button box (first finger = not emotional, second finger = moderately emotional, third finger = strongly emotional and fourth finger = overwhelmingly emotional). Participants could respond with their button-press rating at any time during the 18 s trial. The scanning session comprised four functional runs of approximately 9 min each, with each narrative presented twice (but only once in a given run), for a total of 100 trials. In both the interview and scanning, narratives were shown in pseudorandom order to counterbalance one-back presentation history so that no one condition systematically preceded another. Order of runs during scanning was also counterbalanced.

Word use analyses

Verified transcripts of the interviews were edited to remove the experimenter’s speech and transcription notes, so that only participants’ speech remained. Transcripts were also edited to remove filler words and phrases (e.g. ‘like’, ‘you know’ and ‘I mean’). The edited transcripts were processed using LIWC, which automatically generates word-count rates in multiple categories, including the ‘cognitive words’ and ‘affect words’ categories. LIWC data reflect the percentage of total words devoted to each category; for example, a mean of 10 would indicate that 10% of the words spoken by a participant corresponded to that category.

Functional imaging data acquisition and analysis

Whole-brain images were acquired using a Siemens 3 Tesla MAGNETOM TIM Trio scanner with a 12-channel matrix head coil. Functional scans were acquired using a T₂*-weighted echo planar sequence (TR = 2 s, TE = 30 ms and flip angle = 90°) with a voxel resolution of 3 mm × 3 mm × 4.5 mm. Thirty-two continuous transverse slices were continuously acquired to cover the whole brain and brain stem, with breaks between runs. Anatomical images were acquired

using a magnetization-prepared rapid acquisition gradient sequence (TI = 900 ms, TR = 1950 ms, TE = 2.26 ms and flip angle = 7°) with an isotropic voxel resolution of 1 mm.

Data were processed using SPM8 (Wellcome Department of Cognitive Neurology, London, UK) in MATLAB 2009b (MathWorks, Inc.). Functional images were slice-timing corrected, motion corrected and co-registered to the anatomical image. Anatomical images were segmented and normalized to Montreal Neurological Institute space using tissue probabilistic maps (segmentation, SPM8). The same normalization transformation was applied to the functional images, which were then smoothed using an 8-mm full-width half-maximum (FWHM) Gaussian kernel. Pre-processed BOLD time series were subjected to high-pass filtering (cutoff period 128 s) and session-specific grand mean scaling and were corrected for serial correlation (AR[1] model).

Following Immordino-Yang et al. (2009), each condition was modeled using a finite impulse response function with nine time bins (each bin corresponding to a 2 s TR) to capture the complex neural activity during the 18 s trial. Only emotion trials in which participants indicated feeling emotional (2nd–4th finger button press) and control trials in which participants reported not feeling emotional (1st finger button press) were included. Excluded trials were modeled as a separate condition of no interest.

Fixed-effect models were run at the individual level. The sums of parameter estimates corresponding to the 4th–8th TRs (6–16 s post-trial onset, the time window previously shown in Immordino-Yang et al. (2009) to capture the emotion-related BOLD responses in this task) were used to create contrast maps. To test our main neural hypothesis, we calculated a combined contrast of all emotion conditions *vs* implicit baseline and entered individuals’ contrast maps into a group-level whole-brain regression analysis using the affect-cognitive speech variable as a covariate (weighted at ‘1’). The resulting statistical map was corrected for multiple comparisons at a false discovery rate of $q < 0.05$, which resulted in a t threshold of $t = 2.62$. Resulting map was displayed on a three-dimensional template brain; we confirmed the anatomical localization of our results with an expert in neuroanatomy, Hanna Damasio. See Table 1 and Figure 2 for results.

To ensure that our main finding was not driven by a subset of emotion conditions, we repeated the analysis with separate contrasts for each emotion condition *vs* implicit baseline. We applied the critical t threshold from the main contrast (i.e. all emotions *vs* baseline, $t = 2.62$) and examined our hypothesized regions of interest. See Table 2 for results.

RESULTS

Word use

About 7% of the words spoken by participants during the interview were categorized as affect words (mean = 6.71, range: 4.41–10.01, s.d. = 1.39). Cognitive words comprised about 20% of participants’ speech (mean = 21.28, range: 17.67–24.49, s.d. = 1.88). We examined the valence of affect words used by participants and found that use of negative and positive affect words was correlated, $r(26) = 0.47$, $p = 0.01$.

Cognitive and affect word use rates displayed high intra-individual stability across the five conditions (four emotion conditions and control; Cronbach’s α : 0.80 for cognitive and 0.83 for affect words). When cognitive words across the conditions were entered into principal component analysis, a single factor emerged (eigenvalue = 2.83); a single factor also emerged for the five conditions of affect words (eigenvalue = 3.01). Therefore, as expected, both cognitive and affect word use appear to show individual stability across the different emotions induced during the interview.

Table 1 MNI coordinates and effect sizes of peak correlations between word use and BOLD for the contrast of emotion conditions combined vs implicit baseline. Results are from a whole-brain analysis, organized into regions that were hypothesized and all others. Results are thresholded at $q(\text{FDR}) < 0.05$ (corresponding to a critical t value of 2.62) with a minimum cluster size of 10 voxels

Hypothesized regions					Other regions				
	X	Y	Z	z-score		X	Y	Z	z-score
Postcentral gyrus (SI)	−14	−32	72	3.77	Gyrus rectus	−6	52	−10	2.71
	18	−42	68	4.26	MFG	38	48	32	3.30
	32	−32	58	3.84	mOrbG	−20	42	−16	3.19
Parietal operculum (SII)	−54	−24	16	4.38		18	32	−8	2.90
	52	−22	24	3.93	MTG	−62	−18	−12	3.96
	−44	0	6	4.09	STS	54	−2	−14	3.90
Insula	−32	28	−4	3.88	SFG	−12	−2	60	3.61
	−34	−20	14	3.12		22	6	64	4.17
	40	12	0	3.01	Postcentral gyrus (MI)	−4	−18	70	3.79
Anterior cingulate cortex	36	−18	8	3.69		22	−14	72	4.11
	4	−2	46	4.07	Occipitoparietal sulcus	−12	76	32	4.68
						20	−70	36	5.11
					Lingual gyrus	−22	−54	−2	3.14
						12	−64	2	3.25
					Amygdala/Hippocampus	−24	−2	−16	2.99
						22	−6	−16	2.69
					Mesencephalon	−10	−28	−4	2.81
						14	−20	−6	2.92
						−12	−34	−36	2.81
					Cerebellum	−24	−56	−50	2.96
						20	−50	−30	3.35

Note: MFG: middle frontal gyrus; mOrbG: middle orbital gyrus; MTG: middle temporal gyrus; STS: superior temporal sulcus; SFG: superior frontal gyrus.

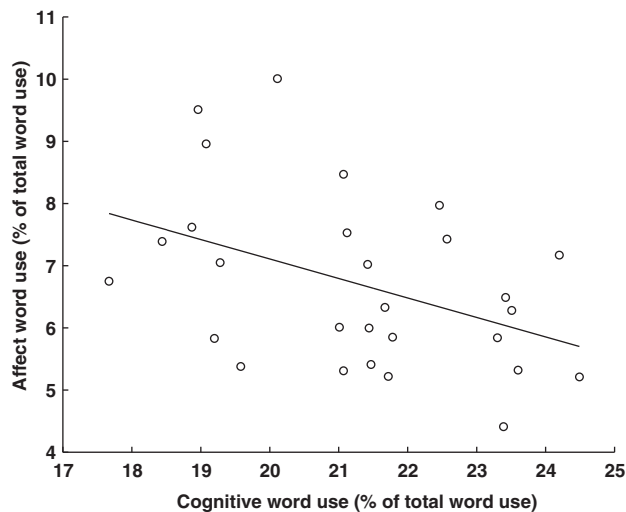


Fig. 1 Scatterplot illustrating the inverse relationship between 'affect' and 'cognitive' word use over the course of the pre-scan interview, $r(26) = -0.43$, $p = 0.02$. Each plotted point represents one participants' data for all experiment conditions combined (i.e. all emotion conditions and control social processing).

Given the high stability of word use across conditions, affect and cognitive words were totaled across all conditions. As shown in Figure 1, the total counts of affect words were negatively correlated with totals for cognitive words, $r(26) = -0.43$, $p = 0.02$. Because of this finding, counts for these two categories of words were combined into a single variable situating each individual in terms of his or her relative use of affective vs cognitive speech. This variable, which had a mean of 0.0 (range: -2.78 to 3.25 , $SD = 1.69$), was created by calculating z-scores across participants for both the cognitive words and the affect words categories and then subtracting the cognitive words z-score from the

affect words z-score. This variable was then correlated with BOLD (see subsequent sections).

Neither affect words, cognitive words, nor the combined variable, correlated with participants' age, gender or ethnicity, with the exception that women used more cognitive words (at a marginal level of significance; $r(26) = 0.35$, $p = 0.07$).

No significant associations emerged between button-press ratings of experienced emotion strength in the scanner and cognitive or affect word use, or the combined variable. Correlation coefficients ranged from 0.03 to 0.18 and all p values exceeded 0.35.

Main effect of emotion vs baseline on BOLD

We examined contrasts of each emotion condition vs baseline and the control condition vs baseline. In each case we found extensive supra-threshold activations that covered virtually the entire brain including our hypothesized regions and no significant deactivations. Therefore, any positive correlations between word use and BOLD reflect a relationship with the positive-going BOLD signal and not with a lessening of BOLD suppression.

Associations between word use and BOLD

Neuroimaging results revealed significant associations in our hypothesized regions of interest between the combined word use variable and activation during each of the emotion conditions vs baseline, as well as with the combined emotion conditions vs baseline.

In each emotion condition, BOLD activity in the primary and secondary somatosensory cortices (SI and SII), the insula and the ACC was associated with the combined word use variable (see Table 2). The locations of peak positive association in each contrast generally did not overlap. Together, these results suggest that our findings are not driven by neural responses to a particular type of social emotion, e.g. pain-based or pleasurable.

Table 2 MNI coordinates and effect sizes of peak correlations between word use and BOLD for the contrasts of each emotion condition vs implicit baseline, hypothesized regions only

Region	AV				AS				CSP				CPP			
	X	Y	Z	z-score	X	Y	Z	z-score	X	Y	Z	z-score	X	Y	Z	z-score
Postcentral gyrus (SI)	−30	−34	70	4.08	−14	−28	64	3.64	−12	−46	60	3.14	−18	−44	66	3.71
	−12	−38	60	3.68					−36	−30	68	2.72				
	10	−42	68	4.39	18	−44	64	3.28	12	−42	70	3.47	20	−40	66	3.80
	32	−30	60	3.74					50	−30	60	3.42	56	−24	54	4.23
Parietal operculum (SII)	−50	−26	14	3.47	−66	−24	22	3.30	−54	−26	18	3.51	−54	−22	20	3.97
	50	−20	16	3.75	64	−22	18	3.41	50	−24	26	3.12	56	−30	16	4.10
Insula	−40	−6	6	2.93					−44	−2	6	3.45	−44	−2	6	3.83
	−36	−22	16	3.31					−26	26	−4	3.27	−32	28	−4	4.22
	40	10	0	2.87	46	−10	8	2.73					40	−4	−2	3.12
	36	−26	22	3.29									38	−20	10	3.08
Anterior cingulate cortex	6	0	46	3.44	2	−2	44	3.06	6	0	46	3.90	6	−6	48	3.90

Results are thresholded using a critical *t* value of 2.62 (the *t* threshold that corresponds to *q*(FDR) < 0.05 in the main analysis of emotions combined vs baseline) with a minimum cluster size of 10 voxels.

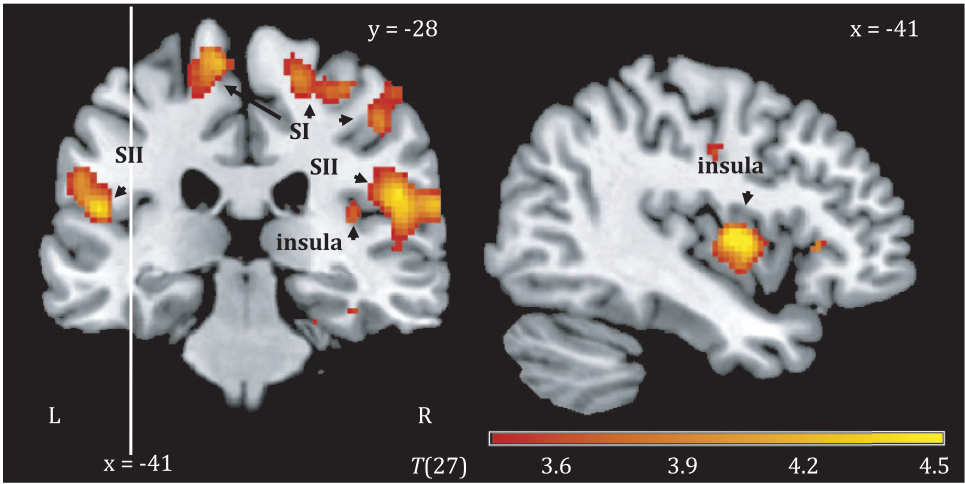


Fig. 2 Representative images of brain regions whose activity level for emotion relative to baseline correlates with individual differences in word use during the pre-scan interview. For display purposes, results are thresholded at *p* < 0.001 (corresponding to a critical *t* value of 3.43), with a minimum cluster size of 10 voxels. Red to yellow indicates more BOLD activity during participant-reported emotion for participants who used more affective relative to cognitive words during the interview. The vertical line in the left panel indicates the position of the sagittal slice.

Table 1 presents all suprathreshold clusters that correlated with the speech variable for the contrast of the combined emotion conditions vs baseline. Figure 2 presents representative images of this result.

The combined word use variable was not associated with the BOLD responses to the control narratives, with the exception of one cluster in SII (*x* = 68, *y* = −24, *z* = 16 and *z*-score = 3.14), suggesting that our effects are specific to emotion processing, not processing of narratives more generally (e.g. driven by mnemonic demands).

DISCUSSION

This study examined spontaneous affective and cognitive language use during emotion induction interviews and associations with activation in somatosensory (including interoceptive) brain regions. Rates of cognitive words and affect words showed stability within individuals across the different varieties of emotions induced, suggesting that these word rates reflect reliable individual differences in emotion processing. Across participants, use of cognitive words was negatively associated with use of affect words, and people who used more affect words, relative to cognitive words, showed greater activation in somatosensory areas during emotion. Importantly, cognitive and affect word use rates were not associated with button-press ratings of

emotion strength in the scanner and did not predict brain activation during control social processing (in which participants reported feeling unemotional). Together, these findings suggest that these word use patterns reflect distinct styles of emotion processing and not simply the intensity of individuals' emotions in relation to our stimuli. In addition, the lack of relationship between BOLD and speech style during the control condition suggests that our effect is specific to emotion and not attributable to memory or other cognitive processing that would be equivalent between the emotion and control conditions of our experiment.

The areas of activation that correlated with affective, relative to cognitive, language use included the SI, SII, insula and middle ACC—all somatosensory areas that have been associated with the processing of emotions. The insula is involved in interoceptive body awareness and thus in feeling emotions (e.g. Damasio, 1999, 2005; Damasio et al. 2000; Craig, 2009; Harrison et al., 2010), including social emotions such as empathy for others' pain (Singer, 2006; Immordino-Yang, et al., 2009). The middle ACC is involved in the perception of bodily pain (Talbot, et al., 1991; Baliki et al., 2006) and related to individual differences in emotional awareness (e.g. Lane et al., 1998; McRae, et al., 2008). Somatosensory cortices have been implicated in emotional judgments of other people (Adolphs et al.,

2000), and insula lesions have been related to difficulty discerning disgust from others' facial expressions (Calder et al., 2000). Our findings suggest that these somatosensory areas are recruited particularly strongly during emotion processing by some people, possibly to create a more embodied emotional style. Importantly, we did not study embodied language specifically (e.g. descriptions of physical body sensations), but affective language as a possible marker of reliance on somatosensation during emotion processing.

Our results reveal associations between a more affective linguistic style when describing emotional feelings and subsequent neural activations during re-creations of the same emotions. However, in a whole-brain analysis, we did not find any brain regions that showed greater activity associated with higher cognitive, relative to affective, language use. We also found only negative associations when we examined cognitive words as a separate variable, whether or not we adjusted for affective word use. Follow-up investigations that focus on smaller subcategories of cognitive words, for example words associated with a particular cognitive process like perspective taking, might help to resolve the question of whether high cognitive language use in our study reflects the use of one or more processing strategies that are distinct from each other, or even negatively related, but that are together inversely correlated with affective words. If these subcategories of cognitive style are found, they could potentially be correlated with the relative recruitment of various neural systems involved in social cognitive processing.

This study had several additional limitations. We used a continuous variable reflecting the proportion of affective to cognitive words, but future studies could stratify individuals into groups based on their speech styles and explore between-group differences in neural activation and in other characteristics, e.g. personality and social relationship quality. Another unanswered question is whether individuals' rates of cognitive and affective speech in our interviews would generalize to their language use and behavior in other contexts. Our interview protocol did present a constrained, laboratory-based experimental context (by necessity); however, participants were not told what emotions we aimed to induce, they were not given a questionnaire with forced choices and they could answer the question of how they felt using spontaneous, naturalistic language. This design was meant to capture participants' spontaneous approaches to understanding unknown others' social situations, but its real-world validity remains to be tested.

This study contributes to the literatures on individual differences, open-ended language use and the neural processing of social emotions in several important ways. To our knowledge, this is the first article using fMRI to explore the neural correlates of linguistic style. Given that studies of language use using quantitative approaches have yielded fruitful insights in other domains of psychology, including health psychology and personality psychology (Tausczik and Pennebaker, 2010), this study offers 'proof of concept' that the linguistic properties of individuals' open-ended speech can be connected with their subsequent patterns of neural activation.

In addition, the association we found between affectively charged language and neural embodiment when experiencing emotion has implications for understanding how emotional styles contribute to the allostatic function of social emotions such as admiration, compassion and others. Further studies could address how individual differences develop, the possibility of differences by valence, possible relations to genetic or other biological propensities (such as for somatosensory acuity) and the possibility of cultural differences. This line of research may also have clinical implications. For example, linguistic analysis studies have found that people tend to use more cognitive words after a traumatic event (e.g. Gortner and Pennebaker, 2003; Boals and Klein, 2005), which may reflect an adaptive strategy for

establishing mental distance from overwhelming emotions. Understanding how this strategy may change emotion-related neural processing in response to traumatic events would be useful in developing and assessing interventions. In addition, understanding how individuals differ in their reliance on cues from the physical body during the experience of emotion might also inform research on psychosomatic illness (de Greck et al., in press) and anxiety, which have been linked to interoceptive awareness (Ehlers, 1993; Herbert and Pollatos, 2012).

In conclusion, this study demonstrates the power of using spontaneous language use to understand individual differences in the neural correlates of complex social emotional processing. It is also the first study to reveal that individuals differ on the extent to which they are neurally 'embodied' during the feeling of strong emotions. Further research into natural language use and its neural correlates may therefore inform our understanding of how the mind and body work together during the experience of emotion.

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