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The Neural Representation of Abstract Words: The Role of Emotion

Gabriella Vigliocco[1], Stavroula-Thaleia Kousta[2], Pasquale Anthony Della Rosa[3], David P. Vinson[1], Marco Tettamanti[3], Joseph T. Devlin[1] and Stefano F. Cappa[3]

[1]Cognitive, Perceptual and Brain Sciences Research Department, Division of Psychology and Language Sciences, University College London, London WC1H OAP, UK, [2]Trends in Cognitive Sciences, Cell Press, Cambridge, MA 02142, USA and [3]Vita-Salute University and San Raffaele Scientific Institute, DIBIT, Milan 20132, Italy

Address correspondence to Gabriella Vigliocco, Cognitive, Perceptual and Brain Sciences Research Department, Division of Psychology and Language Sciences, University College London, London, UK. Email: g.vigliocco@ucl.ac.uk

It is generally assumed that abstract concepts are linguistically coded, in line with imaging evidence of greater engagement of the left perisylvian language network for abstract than concrete words (Binder JR, Desai RH, Graves WW, Conant LL. 2009. Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. Cerebral Cortex. 19:2767–2796; Wang J, Conder JA, Blitzer DN, Shinkareva SV. 2010. Neural representation of abstract and concrete concepts: A meta-analysis of neuroimaging studies. Hum Brain Map. 31:1459–1468). Recent behavioral work, which used tighter matching of items than previous studies, however, suggests that abstract concepts also entail affective processing to a greater extent than concrete concepts (Kousta S-T, Vigliocco G, Vinson DP, Andrews M, Del Campo E. The representation of abstract words: Why emotion matters. J Exp Psychol Gen. 140:14–34). Here we report a functional magnetic resonance imaging experiment that shows greater engagement of the rostral anterior cingulate cortex, an area associated with emotion processing (e.g., Etkin A, Egner T, Peraza DM, Kandel ER, Hirsch J. 2006. Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. Neuron. 52:871), in abstract processing. For abstract words, activation in this area was modulated by the hedonic valence (degree of positive or negative affective association) of our items. A correlation analysis of more than 1,400 English words further showed that abstract words, in general, receive higher ratings for affective associations (both valence and arousal) than concrete words, supporting the view that engagement of emotional processing is generally required for processing abstract words. We argue that these results support embodiment views of semantic representation, according to which, whereas concrete concepts are grounded in our sensory–motor experience, affective experience is crucial in the grounding of abstract concepts.

Keywords: abstract words, anterior cingulate cortex, emotion processing, fMRI, lexical decision, rostral ACC, semantic memory

Introduction

The distinction between concrete and abstract entities is an ontological distinction based on whether the concepts refer to something that can be perceived and acted upon or whether it is only internally represented (Hale 1988). What makes humans capable of representing abstract concepts? One obvious candidate is language, a symbolic system allowing knowledge not referring to the here and now, to be learnt and shared. After all, it is obvious that we learn abstract words and concepts by being told what they mean (e.g., in school) or by implicitly extracting statistical information regarding their meaning from linguistic input (Andrews et al. 2009). Indeed, abstract words tend to be learnt later than concrete words, once language is solidly established, and formal education has begun. According to Age of Acquisition norms (i.e., judgments by adult native speakers on when they acquired given words; Stadthagen-Gonzalez and Davis 2006), only 10% of 3-year-olds' vocabulary is abstract, rising to 25% in 5-year-olds. Acquisition of abstract concepts then increases steadily: >60% of 11-year-olds' vocabulary is abstract. Two dominant cognitive theories of the differences between concrete and abstract concepts and words, namely the Dual Coding theory (Paivio 1971, 2007) and the Context Availability hypothesis (Schwanenflugel and Shoben 1983; Schwanenflugel 1991), agree in assuming that linguistic processing plays a pivotal role in learning and processing abstract concepts. These theories differ with regards to how differences between concrete and abstract processing come about. Dual Coding argues that concrete words would be represented in two distinct formats, a verbal and a non-verbal, imagistic, code, whereas abstract concepts would be primarily or solely represented in a verbal code (e.g., Paivio 2007). In contrast, Context Availability accounts for differences between concrete and abstract concepts as a consequence of how they are represented in verbal memory, with stronger and denser associations with contextual knowledge for concrete than abstract words (Schwanenflugel 1991).

Imaging studies in general provide evidence supporting the idea of a greater role of linguistic processing for abstract concepts. Abstract processing has been associated with higher activation in left hemispheric areas involved in linguistic processing/verbal semantics such as the left inferior frontal gyrus (e.g., Perani et al. 1999; Jessen et al. 2000; Fiebach and Friederici 2003; Noppeney and Price 2004; Binder et al. 2005) and the superior temporal cortex (Mellet et al. 1998; Kiehl et al. 1999; Wise et al. 2000; Binder et al. 2005; see Binder et al. 2009 and Wang et al. 2010 for reviews and meta-analyses). Recent lesion and transcranial magnetic stimulation work further converge in supporting a role for the left ventrolateral prefrontal cortex in the processing of abstract words and concepts (Hoffman et al. 2010).

It is, however, the case that in these previous studies abstract stimuli tended to differ from concrete words on a number of additional dimensions. For example, whereas most studies controlled for differences in frequency between concrete and abstract words, many of the studies above did not control for differences in familiarity, leading to comparisons between more familiar (and therefore easier to process) concrete (e.g., *artichoke*) and less familiar, abstract (e.g., *heresy*) words. Moreover, in the literature it is invariably assumed that the psycholinguistic constructs of concreteness and imageability tap into the same underlying theoretical construct, i.e., the ontological distinction between concrete and abstract entities. Thus, concreteness and imageability ratings have been used interchangeably (e.g. Richardson 2003; Giesbrecht et al. 2004; Binder et al. 2005; Fliessbach et al. 2006). While we recognize that these differences between concrete and abstract words are important and highly correlated with concreteness, it is also the case that they do not exhaust the dimensions along which concrete and abstract words differ. Concreteness and imageability tap into, at least partially, different aspects of semantic representations. In particular, the distribution of concreteness ratings is bimodal, capturing the categorical ontological distinction between concrete and abstract concepts, whereas the distribution of imageability ratings is unimodal, indexing the graded amounts of sensory (primarily visual) associations of words (see Fig. 1 in Kousta et al. 2011). It is therefore the case that these two constructs are only interchangeable within theories that assume that abstract and concrete words differ only in terms of the degree of engagement of imagistic system (i.e., imageability) (Paivio 1971, 2007).

In previous behavioral work, Kousta et al. (2011) reexamined differences between concrete and abstract word recognition, controlling for a larger number of lexical and sublexical dimensions, which critically included familiarity, context availability (ratings of how many contexts one can think of for a given word), and imageability. In addition, norms for mode of acquisition (i.e., ratings by adult native speakers of the extent to which a given concept has been learnt primarily via language or via experience on a 1–7-point scale; Della Rosa et al. 2011) were also used. In lexical decision experiments, it was found that once these variables that, jointly, tend to favor concrete word processing are taken into account, abstract words are processed *faster* than concrete, resulting in a reversal of the more typical concreteness effect. As one may worry that experiments in which items are controlled to this extent use atypical items, Kousta et al. (2011) further demonstrated that this reversal of the concreteness effect in regression analyses of lexical decision response times (RTs) for a large number of words ($n = 2330$) from the English Lexicon Project (Balota et al. 2007).

Crucially, Kousta et al. (2011) found that the processing advantage for abstract words was due to differences in emotional valence (whether the words have positive, negative, or no emotional associations) between concrete and abstract words. In their Experiment 3, including 480 words spanning the entire range of concreteness and valence ratings, the effects of concreteness (i.e. faster responses for abstract than concrete words) disappeared when valence was included as a predictor. In other words, the advantage for abstract words was mediated by their greater affective associations. In previous work, greater affective associations have been shown to facilitate word processing (Kanske and Kotz 2007; Kousta et al. 2009) in lexical decision tasks. Thus, these behavioral results indicate that differences in terms of linguistic information do not exhaust the differences between concrete and abstract concepts, given that these are still processed differently after controlling for variables such as imageability, context availability, and mode of acquisition. Rather, they suggest that affective information may also play a critical role.

On the basis of these findings, Kousta et al. (2011) and Vigliocco et al. (2009) have proposed an *embodied* theory of the representation of abstract words and concepts. Embodied theories of cognition (of which Dual Coding Theory is an early example) propose that cognition is grounded in bodily states, modal simulations, and situated action (Barsalou 1999; Barsalou et al. 2003; Rizzolatti and Craighero 2004; Decety and Grezes 2006; Gibbs 2006) and find support in a growing body of evidence (see, e.g., Martin 2007, 2009; Binder and Desai 2011; Meteyard et al. 2012, for reviews). Embodied approaches clearly apply to the representation and processing of concrete concepts. It is less obvious, however, how abstract concepts can be embodied. In Kousta and colleagues' proposal, the difference between concrete and abstract concepts come about because of a statistical preponderance of sensorimotor associations underlying concrete word meanings and a statistical preponderance of affective (and linguistic) associations underlying abstract word meanings. In this approach, knowledge about concrete objects and actions would develop from our experience with the external world and would be grounded in the same neural systems mediating our physical experience. In contrast, our internal affective experience would provide at least initial grounding to abstract concepts (which refer to internal experience not limited to emotions). Thus, abstract concepts would be rooted in the same neural system mediating processing of nonlinguistic emotions. Emotion could play an especially important role during language acquisition: words that denote emotional states, moods, or feelings could provide initial examples of how a word may refer to an entity that is not externally observable but resides within the organism. This may provide a crucial stepping stone in the development of the ontological distinction between entities existing in the physical world and those existing only in the human mind, namely abstract entities. Consistent with this possibility, abstract words denoting emotional states are the first abstract words to emerge during language development (Bretherton and Beeghly 1982; Wellman et al. 1995; Kousta et al. 2011).

Here, we assess whether abstract words engage the affective system by virtue of having more affective associations than concrete words. In a functional magnetic resonance imaging experiment we manipulate the concreteness but not the affective associations of the items used, controlling for the same large number of other lexical and sublexical factors as in Kousta et al. (2011).

Methods

Preliminary Study

Kousta et al. (2011) showed that, once a large number of factors are controlled, abstract words are processed faster than concrete words because of their greater affective associations. However, how general is the link between concreteness and emotion? One could argue that such a link is present only for a specific type of items: the most familiar and imageable abstract words that refer to emotion (such as *love*, *anger*, *happiness*). Because of the strict selection criteria used in the previous studies and, in the current study, one can argue that there is a bias toward abstract words that strictly refer to emotion. Thus, given a large enough set of words, valence and arousal ratings would not predict concreteness ratings.

To assess the generalizability of the link between affective associations and concreteness, we carried out regression analyses for 1,446 English words, spanning the concreteness and the valence/arousal continua. The number of words included in these analyses was only constrained by the availability of normative data for concreteness, valence, and arousal. Concreteness ratings were obtained from the MRC Psycholinguistic Database (Coltheart 1981; Wilson 1988, downloaded from www.psy.uwa.edu.au/uwa_mrc.htm on 24 May 2007).

Valence and arousal ratings (on a scale from 1 to 9; for valence: 1 = negative, 5 = neutral, 9 = positive; for arousal: 1 = low arousal, 9 = high arousal) were taken from published norms (ANEW, Bradley and Lang 1999) and from additional norming we carried out following the same procedure (see Kousta et al. 2011 for details). In the regression analyses, we modeled both linear as well as nonlinear relationships between predictors and dependent variable (previous work has shown that valence is best modeled as a U-shaped function from negative to neutral to positive, Lewis et al. 2007; Kousta et al. 2009, 2011). Nonlinear relationships were modeled using restricted cubic splines (Harrell 2001).

First, we looked at zero-order correlations between valence and concreteness (arousal and concreteness in different models), using ordinary least squares regression. Both linear and nonlinear components were significant predictors (overall $F_{2,1443} = 40.4$, $P < 0.0001$; nonlinear $F_{1,1443} = 60.6$, $P < 0.0001$; adjusted $R^2 = 0.052$). Valenced words tend to be more abstract, whereas neutral words tend to be more concrete. For arousal, only the linear arousal term was included in the final model ($F_{1,1444} = 93.8$, $P < 0.0001$, $R^2 = 0.060$). We then looked at the partial effect of valence (or arousal in different models) after all other lexical and sub-lexical factors (including arousal) were taken into account. Unsurprisingly, imageability was the strongest predictor ($F_{1,1430} = 2439$, $P < 0.0001$), along with familiarity ($F_{2,1430} = 72.5$, $P < 0.0001$) and number of morphemes ($F_{1,1430} = 11.9$, $P = 0.0006$); adjusted R^2 for the full model = 0.788. Importantly, the unique effect of valence remained significant in this model: valenced words tended to be more abstract even after accounting for other relevant factors (overall partial effect of valence $F_{2,1430} = 52.9$, $P < 0.0001$; nonlinear $F_{1,1430} = 101.4$, $P < 0.0001$; Fig. 1*A*). The unique effect of arousal also remained significant: arousing words tend to be more abstract ($F_{1,1430} = 98.1$, $P < 0.0001$; Fig. 1*B*).

These results do not imply that emotion is the only factor differing between concrete and abstract words, as other factors (most clearly imageability and familiarity) were also significant predictors of concreteness ratings. Importantly, however, emotion is the only factor giving abstract words an advantage: abstract words are less imageable, less familiar, acquired later but they are more emotional than concrete words (which gives them a processing time advantage, Kousta et al. 2011).

Main Experiment

Subjects

Twenty right-handed native English speakers (mean age = 21.9 ± 4.4 years [range: 18–33]; 4 males, 16 females) with normal hearing and vision, no history of neurological or psychiatric illness, and no early exposure to a second language participated in the study. All provided written informed consent and were paid for their participation. The study was approved by the NHS Berkshire Research Ethics Committee.

Stimuli

Sixty abstract and 60 concrete nouns were selected that differed significantly in concreteness but were matched for all other lexical and sublexical variables that are thought to affect visual word recognition, including ratings of imageability, context availability, and mode of acquisition (i.e., judgments of the extent to which a word's meaning is learned perceptually or linguistically—Della Rosa et al. 2011). Table 1 provides a list of all the variables that were controlled. As affective associations (both valence and arousal) were not manipulated nor controlled, concrete and abstract words in our set differed with respect to valence and arousal, with abstract words being more valenced and more arousing than concrete words (see Table 1). The full list of items used in the experiment is available as Supplementary Material. It is important to note here that because of the high correlation between concreteness, imageability, and familiarity, it is the case that by controlling for all these factors, there is the potential for reducing the generalizability of findings.

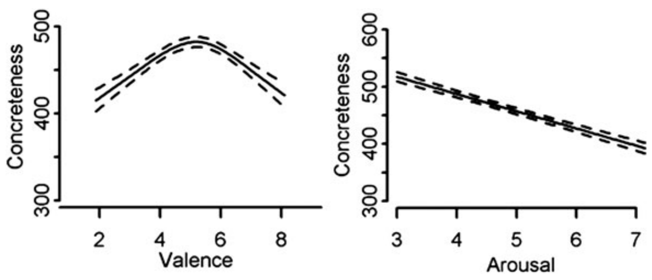

Figure 1. Relationship between valence (or arousal) and concreteness ratings. Left panel: Partial effect of valence as a predictor of concreteness after all other lexical and sublexical factors (including imageability and familiarity) are taken into account. Right panel: Partial effect of arousal as a predictor of concreteness after all other lexical and sublexical factors (including imageability and familiarity) are taken into account. Dashed lines indicate 95% highest posterior density confidence interval for parameter estimates.

Table 1
Lexical and sublexical properties of words used (mean value; standard deviation in brackets) and two-tailed *P*-value for *t*-tests comparing abstract with concrete

	Abstract	Concrete	*P*-value
Imageability[a,b]	496.2 (45.7)	500.0 (48.2)	0.460
Context availability[a]	567.1 (50.3)	561.2 (52.4)	0.491
Familiarity[a,b]	498.1 (74.1)	491.8 (77.1)	0.393
Age of acquisition[a,b]	402.6 (89.6)	411.4 (103.7)	0.928
Mode of acquisition[c]	417.6 (90.5)	397.8 (88.9)	0.124
Log frequency (HAL)[d]	8.65 (1.73)	8.77 (1.74)	0.549
No. orthographic neighbors[d]	2.20 (3.55)	2.37 (3.76)	0.552
Sum Bigram frequency[d]	9651 (5543)	9653 (5654)	0.998
Mean Bigram frequency[d]	1741 (685)	1754 (787)	0.917
Sum Bigram by position[d]	1743 (1052)	1709 (892)	0.795
No. of morphemes[d]	1.25 (0.51)	1.20 (0.44)	0.370
No. of letters	6.20 (1.65)	6.22 (1.70)	0.799
No. of phonemes[d]	5.17 (1.50)	5.02 (1.70)	0.402
No. of syllables[d]	1.87 (0.77)	1.82 (0.81)	0.594
Concreteness[a]	345.3 (42.1)	550.8 (37.8)	<0.001
Hedonic valence[e,f]	1.83 (0.85)	0.65 (0.62)	<0.001
Arousal[e]	5.72 (1.11)	4.54 (0.74)	<0.001

[a] From MRC psycholinguistic database (Coltheart 1981; Wilson 1988: www.psy.uwa.edu.au/uwa_mrc.htm).

[b] From Stadthagen-Gonzalez and Davis (2006).

[c] Unpublished data (Kousta et al. 2007), collected following procedures described in Della Rosa et al. (2011).

[d] From English Lexicon Project (Balota et al. 2007: exlexicon.wustl.edu).

[e] From Bradley and Lang (1999) and unpublished data described in Kousta et al. (2009).

[f] Hedonic valence = distance from neutrality.

Ninety orthographically legal pseudowords were also created, with similar characteristics to the words. For each target word, we selected a different word matched in length and concreteness, and changed one letter, resulting in a pronounceable nonword. We used WordGen (Duyck et al. 2004) to ensure that these pseudowords were matched with the original target words in mean bigram frequency, and had as few orthographic neighbors as possible (only one, the target word, for all pseudowords 5 letters or longer). Finally, we also created 30 nonpronounceable letter strings, made up of randomly selected consonants, whose lengths (in letters) were representative of the target word set.

Procedure

The task was visual lexical decision. Stimuli were presented on a computer screen and participants made their responses using a button box. On each trial, a fixation cross was first displayed for 500 ms. The target word was then displayed for 500 ms then replaced by a question mark which was displayed for 2,000 ms. Then, the screen was cleared, and a blank screen remained for a random interval ranging from 1000 to 5000 ms. RTs were measured as the time of the first key press after word onset. Analyses of RTs are reported below. Lexical decision trials were arranged into blocks of 12 trials each, between which a rest signal "***" appeared for 14 s. After every 6 or 7 blocks, there was a longer break of 30 s. Words, pseudowords, and letter strings were fully randomized across trials for each subject. As all subjects responded highly accurately (lowest subject, 84% correct), and no items were at chance level (lowest item, 64% correct), no subjects or items were excluded from analysis due to performance level.

Imaging Methods

Whole-brain imaging was performed on a Siemens 1.5 Tesla MR scanner at the Birkbeck-UCL Neuroimaging (BUCNI) Centre in London. The functional data were acquired with a gradient-echo echo planar imaging (EPI) sequence ($TR = 3000$ ms; $TE = 50$ ms, $FOV = 192 \times 192$, $matrix = 64 \times 64$, 35 slices) giving a notional resolution of $3 \times 3 \times 3$ mm. Each run consisted of 197 volumes and as a result, the three runs together took 20 min. In addition, a high-resolution anatomical scan was acquired (T_1-weighted FLASH, $TR = 12$ ms; $TE = 5.6$ ms; 1 mm^3 resolution) for anatomically localizing activations in individuals. Data were preprocessed and analyzed using statistical parametric mapping 5 (SPM5) (Statistical Parametric Mapping; Wellcome Department of Cognitive Neurology, London, UK). Prior to analysis, all images for all three sessions underwent a series of preprocessing steps. Time series diagnostics using tsdiffana (Matthew Brett, MRC CBU: http://imaging.mri-cbu.cam.ac.uk/imaging/DataDiagnostics) were run to verify the quality of the functional data. Data from three subjects had to be discarded due to excessive motion and noise, leaving 17 subjects.

For each scanning session, all functional volumes were realigned to the first one in the time series. High-resolution anatomical T_1 images were coregistered with the realigned functional images to facilitate spatial normalization. Moreover, the mean EPI image of each participant was computed and spatially normalized (Collins et al. 1994; Evans et al. 1994; Holmes et al. 1998) using the "unified segmentation" function in SPM5 (Ashburner and Friston 2005). This algorithm is based on a probabilistic framework that enables image registration, tissue classification, and bias correction to generate a normalization transformation. The spatial normalization parameters for each subject were then applied to the structural and the individual realigned EPI volumes in order to bring them into a standardized montreal neurological institute (MNI) space.

All images were thus transformed into standard MNI152 space and re-sampled to $3 \times 3 \times 3$ mm voxel size. Finally, the T_2*-weighted volumes were smoothed using a Gaussian kernel with 8 mm full-width at half-maximum, in order to account for any residual between-subject variation and increase the signal-to-noise ratio (Friston et al. 1995). The data were analyzed adopting a two-stage random-effects approach to ensure generalizability of the results at the population level (Penny and Holmes 2003). At the individual level, 4 experimental conditions (abstract words, concrete words, pseudowords, and letter strings) were used as separate regressors keeping the rest condition implicit. In addition, to further model first-order variance due to subject movement, the realignment parameters were also included in the design as user-specified regressors. Furthermore, evidence of bad volumes was found for one subject by computing the mean of the squared differences between the corresponding pixels for all pairs of images in the series. This procedure allows identification of large spikes of variance corresponding to those volumes, which are often associated with large movement displacements or severe artifacts. Therefore, a nuisance regressor was added, which consisted of contiguous scans in which artifacts due to movement were detected.

Data Analysis

Direct Contrasts and Conjunction Analysis

A general linear model (GLM) analysis was carried out in which neural activity was modeled as a delta function at stimulus onset. The blood-oxygen-level-dependent (BOLD) response was modeled by convolving these delta functions with the canonical hemodynamic response function (HRF) as implemented in SPM to create regressors of interest. Data were high-pass-filtered at 1/128 Hz to remove low-frequency signal components and were then analyzed with GLM as implemented in SPM5. Temporal autocorrelation was modeled using a first-order autoregressive process. The contrast images from individual subjects were then entered in a one sample t-test to treat subjects as a random effect and account for inter-subject variability in order to assess the significance of the effects at the group level ($n = 17$ participants).

Four contrasts were computed for each subject: ABSTRACT > PSEUDOWORD (A>PW); CONCRETE > PSEUDOWORD (C>PW); ABSTRACT > CONCRETE (A>C); CONCRETE > ABSTRACT (C>A). These were subsequently entered into second-level random effects analyses. Activations were deemed significant if they reached a statistical threshold of $P < 0.005$ at the voxel level and $P < 0.05$ after correction for multiple comparisons [familywise error (FWE)] at the cluster level. The anatomic locations of peak coordinates were initially confirmed by visually inspecting the coordinates overlaid on corresponding slices of the mean structural image of the study sample. The cytoarchitectonically defined location of the local maximum was assessed with the SPM Anatomy Toolbox (Eickhoff et al. 2005). SPM T-maps were projected onto (3D) cortical surface representations obtained by SPM8.

A conjunction analysis over A>PW and C>PW was carried out, using a second-level two sample t-test and testing against conjunction null (Nichols et al. 2005). These two contrasts (A>PW and C>PW) compared highly matched concrete and abstract words to pseudowords that closely resembled real words. This general semantic contrast (Binder et al. 2009) allowed us to delineate the semantic system engaged in processing our abstract and concrete words, in order to assess the generalizability of the resulting activations. Moreover, it provides us with a statistically conservative procedure that increases the power to detect significant activations while eliminating sources of potential artifact (Price and Friston 1996), in order to verify whether both item sets and the experimental design effectively engage the semantic system. The results were assessed at a conjunction threshold of $P < 0.005$ at the voxel level and $P < 0.05$ after correction for multiple comparisons (FWE) at the cluster level ($k = 88$ voxels).

Follow-up Analyses

Words in our set differ for valence and arousal, although this was not manipulated. In follow-up analyses, we assess whether the degree of valence and arousal predicted the signal change. In particular, we carried out: (i) A first regression analysis including all words (abstract and concrete). At the first level, we examined the responses of individual subjects by modeling the presentation times of all words along with three parametric regressors for each word to compute individual SPM maps. The three regressors were the linear component of valence, the quadratic component of valence (more precisely, a second-order polynomial expansion prespecified according to the shape of the valence distribution), and the linear component of arousal ratings. Parameter estimates reflecting the height of the HRF for each of these regressors were calculated at each voxel. The resulting images were used to calculate second-level group contrasts using one-sample *t*-tests identifying the positive main effects of valence and arousal inclusively masked (at $P < 0.005$ uncorrected) in the brain areas activated only by words. (ii) A second regression analysis was carried out to assess the role of valence and arousal in modulating the BOLD signal separately for abstract and concrete words. At the first level, abstract and concrete words were modeled separately along with the 3 parametric regressors. Individual SPM maps were generated separately for abstract or concrete words along with the three parametric regressors. The resulting images were used to calculate second-level group contrasts using one-sample *t*-tests. For abstract words, we assessed the effects of valence and arousal within brain areas activated by words, we masked the A>C contrast specific to each parametric regressor (linear and quadratic valence, arousal) inclusively by the (A + C)>PW contrast (at $P < 0.005$, uncorrected), which highlighted brain regions specific to all words when compared with pseudowords. We could not use the C>A contrast to assess the effects of valence and arousal within brain areas activated solely by concrete words (see Results section for details). We therefore analyzed effects specific to each parametric regressor (linear and quadratic valence, arousal) using the C>PW contrast as an explicit mask (at $P < 0.005$, uncorrected voxelwise, FWE-corrected clusterwise), which included only brain areas significantly responding to concrete words when compared with pseudowords.

Results

Behavioral Results

The behavioral results in the scanner replicated our previous behavioral studies showing faster RTs for abstract than concrete words (Kousta et al. 2011).

Reaction Times

Responses faster than 200 ms and slower than 2000 ms were excluded from analysis (0.32% of the data) as were error trials. Subjects were faster in processing abstract words than concrete words (abstract: 735 ± 34 ms, concrete: 771 ± 35 ms; subjects $t_{(16)} = 3.87$, $P < 0.005$; items $t_{(118)} = 2.39$, $P < 0.05$).

Accuracy Rates

In total, 95.7% (±5.6) of responses to abstract words and 95.1% (±3.8) to concrete words were correct. The difference was not significant (both $|t| < 1$).

Imaging Results

Direct Contrasts and Conjunction Analysis

Both concrete and abstract words engaged largely overlapping networks in the left hemisphere, including the left angular gyrus, middle and inferior temporal gyri, and dorsolateral prefrontal cortex (see Fig. 2*A* and Table 2 for coordinates of peak activations).

In the direct contrast A>C, brain activity peaked in rostral (pregenual) portion of the ACC at 2 local maxima ($x = 12$, $y = 45$, $z = 12$, *Z*-score = 4.15; $x = 0$, $y = 42$, $z = 9$, *Z*-score = 3.05, cluster size = 77 voxels, $P < 0.02$ FWE-clusterwise) (see Fig. 2*B*). The C>A contrast did not produce any significant differences.

The general semantic conjunction analysis revealed a common network including the following regions: the left inferior parietal lobule including the left angular gyrus, the right angular gyrus, bilateral medial orbital-frontal cortex, left frontal superior gyrus, the mid-posterior cingulate cortex extending bilaterally to the precuneus (see Fig. 3 and Table 3). Supplementary Figure S1 presents temporal signal-to-noise ratio average map showing EPI image quality over the whole brain and anterior temporal lobes (ATLs).

Follow-up Analyses

While our claim is that emotion plays a special role in the processing of abstract words, it is obvious that concrete words

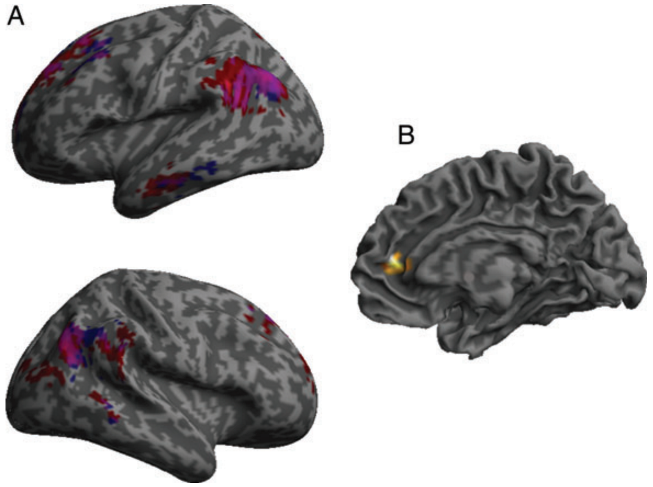

Figure 2. Overall brain activation and differences between abstract and concrete words. (*A*) Areas of greater activation in the left (upper panel) or right (lower panel) hemisphere for the contrast between abstract words and pseudowords (red) and the contrast between concrete words and pseudowords (blue). Areas of overlap between abstract and concrete words minus pseudowords are depicted in violet. (*B*) Significant areas of ABSTRACT > CONCRETE activation. A single activation peak was found in the rostral part of the ACC bilaterally ($x = 12$, $y = 45$, $z = 12$, cluster size = 77 voxels).

Table 2

Coordinates [*x*, *y*, *z* in space of Montreal Neurological Institute (MNI) template] of peak activations for the Abstract>Pseudoword contrast and the Concrete>Pseudoword contrast

Anatomical location	*x*	*y*	*Z*	*Z*-value
Abstract>Pseudoword contrast				
R middle cingulate cortex	9	−45	39	5.39
R angular gyrus	48	−72	30	4.95
L middle frontal gyrus	−27	36	48	4.63
L supramarginal gyrus	−48	−48	30	4.56
R middle frontal gyrus	27	33	39	4.18
R angular gyrus	45	−45	27	3.99
L inferior temporal gyrus	−57	−9	−27	3.92
Concrete>Pseudoword contrast				
R precuneus	9	−51	27	4.62
L middle frontal gyrus	−30	24	45	4.48
L inferior parietal lobule	−36	−75	42	4.43
R superior frontal gyrus	27	33	48	4.13
R angular gyrus	42	−72	39	4.02
L inferior temporal gyrus	−57	−27	−18	3.88
L middle orbital gyrus	0	57	−9	3.72

These coordinates refer to the location of maximal activation indicated by the highest *Z*-score in a particular anatomical structure. (Spatial $P < 0.05$ corrected for multiple comparisons.)

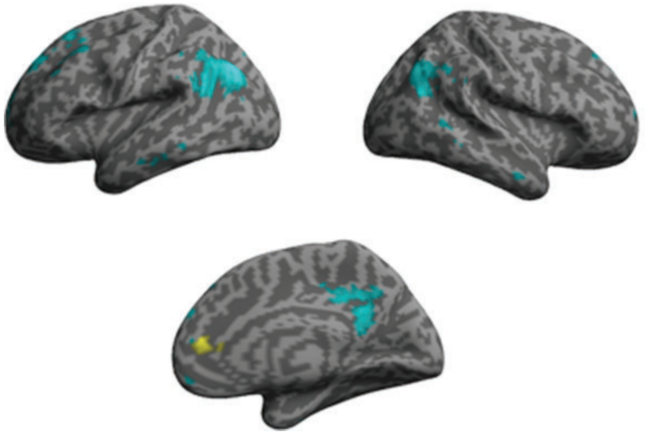

Figure 3. General semantic network. Areas activated in common (cyan) where the two contrasts A>PW and C>PW are hypothesized to isolate the same underlying semantic process. Upper panel: Activation peak in the rostral part of the ACC bilaterally ($x = 12$, $y = 45$, $z = 12$, cluster size = 77 voxels) (yellow) overlaid on the general semantic conjunction SPM map showing that there is no overlap between the activation peak in rACC for A>C and general semantic processing activity common to both abstract and concrete words (displayed at $P < 0.005$, uncorrected and no cluster-wise threshold) (lower panel).

Table 3

Coordinates [*x*, *y*, *z* in space of Montreal Neurological Institute (MNI) template] of peak activations for significant conjoined activations in both abstract and concrete word conditions when compared with pseudowords (PW)

Anatomical location	*x*	*y*	*Z*	*Z*-value
L inferior parietal lobule	−36	−75	42	4.95
R angular gyrus	42	−72	39	4.46
L/R mid orbital gyrus	0	57	−9	4.31
L superior frontal gyrus	−12	45	39	4.29
R precuneus	9	−51	27	4.74
L middle cingulate cortex	0	−42	36	4.01
L precuneus	−3	−57	24	4

These coordinates refer to the location of maximal activation indicated by the highest *Z*-score in a particular anatomical structure. ($P < 0.005$ voxelwise uncorrected for multiple comparisons, and $P < 0.05$ (FWE) cluster-wise corrected.)

Table 4

Coordinates [*x*, *y*, *z* in space of Montreal Neurological Institute (MNI) template] of peak nonlinear modulation effects induced by emotional valence for ALL words observed in brain regions significantly activated by words (inclusive mask thresholded at $P < 0.005$ uncorrected voxelwise)

Anatomical location	*x*	*y*	*Z*	*Z*-value
L inferior occipital gyrus	−33	−78	−9	4.36
L fusiform gyrus	−27	−81	−18	4.06
R inferior occipital gyrus	45	−84	−9	3.99
R Fusiform gyrus	48	−63	−18	3.2
L/R supplementary motor area	3	−3	54	3.52
L middle temporal gyrus	−57	−48	9	3.71
L angular gyrus	−27	−54	36	3.5
L putamen	−21	12	−6	3.89
L insula	−36	−12	6	3.47

These coordinates refer to the location of maximal activation indicated by the highest *Z*-score in a particular anatomical structure. ($P < 0.005$ voxelwise uncorrected for multiple comparisons and cluster extent (k) = 10 voxels.)

can also be emotionally loaded. In order to test for the general role of emotional valence and arousal in word processing, and to look for specific effects on abstract word processing, we carried out the following additional analyses.

In the analysis including all words, one-sample *t*-tests for each parametric regressor revealed only a nonlinear valence-dependent modulation of signal intensity in a network of areas including the inferior occipital gyrus extending to the fusiform and inferior temporal gyrus bilaterally and in the middle temporal gyri, angular gyrus, putamen, and insula in the left hemisphere (see Table 4). No linear relationship was observed between valence or arousal and BOLD signal in any brain area active for processing words. Concerning abstract words, one-sample *t*-tests on the A>C difference for each parametric regressor revealed only a nonlinear valence-dependent modulation of signal intensity in the rostral anterior cingulate cortex (rACC) ($x = 0$, $y = 42$, $z = 6$, $k = 10$, $P < 0.005$ uncorrected voxelwise, *Z*-score = 3.27) at approximately the same peak coordinates revealed in the A>C direct contrast (see above).

To visually examine second-level effects of the parametric regressors for abstract stimuli in the rACC focus of activation highlighted in the A>C contrast, plots of effect sizes for each parametric regressor (valence linear, valence nonlinear, arousal linear) were created using the rfxplot toolbox for SPM5 (Glascher 2009) (http://rfxplot.sourceforge.net/). For illustration purposes, we selected all suprathreshold voxels inside a sphere (12 mm radius) centered on the peak coordinates of the rACC cluster of activation from the direct contrast [rostral anterior cingulate cortex ($x = 12$, $y = 45$, $z = 12$)] and calculated the mean beta values for each participant within the rACC search volume from the individual first-level beta images for each of the three parametric regressors included in the regression analysis. The beta values were then averaged across subjects. Effect sizes for the three parametric regressors within rACC are displayed as percentage of local signal change, and error bars are displayed as ±1 standard error of the mean (see Fig. 4). This analysis showed that only valence, modeled as distance from neutrality (nonlinear), and not arousal, was a significant predictor of signal change. The same toolbox was finally used to compute peri-stimulus time histograms (PSTHs) of the mean event-related response to abstract and concrete trials in the rACC cluster. The PSTHs spanned the peri-stimulus period −3 to 15 s, and the data were split in 3 s time bins corresponding to the TR. The

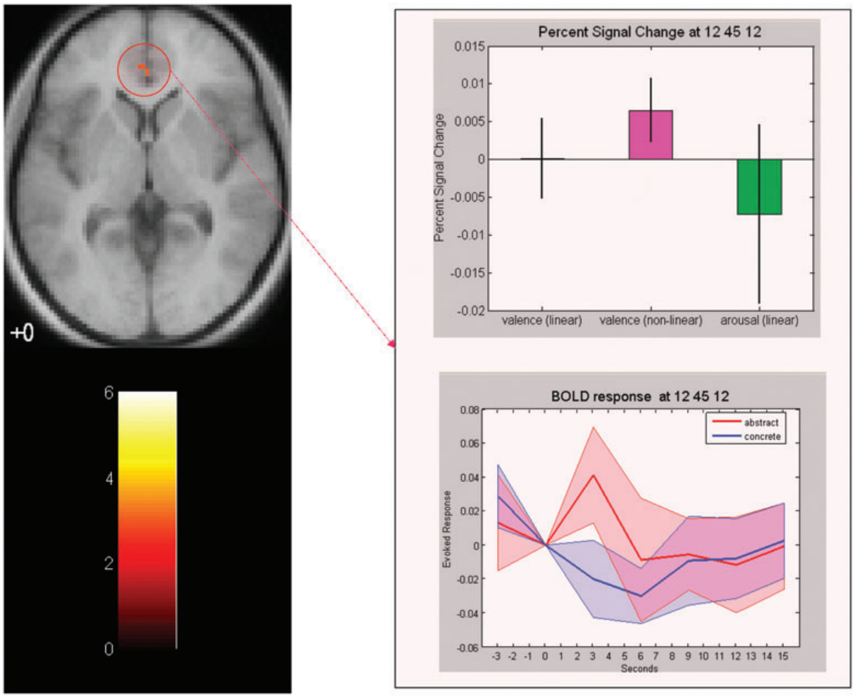

Figure 4. Parametric modulation of brain activity in rACC. Nonlinear valence-dependent modulation for the A>C difference in the rACC projected onto the mean normalized structural scan of all participants ($n = 17$). The graph in the upper right panel shows effect sizes in the rACC of the three parametric regressors referring to abstract words calculated as percentage of local signal change (valence linear = red; valence nonlinear = magenta; arousal linear = green). The graph in the lower right panel shows peristimulus time histograms of evoked BOLD responses in the rACC to abstract (red) and concrete stimuli (blue). This graph represents the average group response, rescaled to 0 at stimulus onset.

colored area around the mean response corresponds to ±1 standard error of the mean response (see Fig. 4). Thus, activation differences between abstract and concrete words in rACC were clearly time-locked to stimulus onset.

The nonlinear relationship between valence and observed BOLD responses was finally assessed separately in brain regions shown to be more active specifically for concrete words as contrasted with pseudowords (C>PW). A significant nonlinear valence-dependent effect was observed in the left supramarginal gyrus ($x = -51$, $y = -51$, $z = 24$, $k = 12$, Z-score = 3.46) and the left precuneus ($x = 0$, $y = -57$, $z = 24$, $k = 10$, Z-score = 3.19). In order to verify the presence of a valence-related effect in the subgenual portion of the ACC (rACC) for concrete concepts as well, a more liberal cluster extent (equal to 5 voxels) was chosen at the same voxel-wise threshold ($P < 0.005$ uncorrected). A significant cluster peaking at $x = -6$, $y = 45$, $z = -12$ (Z-score = 3.31; $k = 5$) was located in a left mid-orbitofrontal region bordering with the rACC (see Supplementary Fig. S2), in a slightly more ventral area with respect to both local maxima observed, respectively, for the main A>C difference ($x = 12$, $y = 45$, $z = 12$) and the A>C valence-dependent nonlinear modulation ($x = 0$, $y = 42$, $z = 6$).

Discussion

The present study shows that differences in the degree and amount of affective associations for concrete and abstract words have processing and neural consequences when other orthographic and semantic variables (which also differ between concrete and abstract concepts) are taken into account.

First, we showed that over a large number of words, abstract words tend to have more affective associations than concrete words. Although this correlation is not strong, indicating that it does not represent the only dimension along which these concepts differ, it is an additional dimension which was not previously identified. Kousta et al. (2011) have argued that the greater amount of affective associations of abstract items can account for processing differences between concrete and abstract words with RTs being faster for abstract than concrete words. Importantly, because words were matched for imageability and context availability, these behavioral results cannot be accounted for by either Dual Coding nor Context Availability, both of which predict no differences between concrete and abstract words under these conditions.

In the neuroimaging data, concrete and abstract words, compared with pseudowords, engaged largely overlapping networks in the left hemisphere including the left angular gyrus, middle and inferior temporal gyri, and dorsolateral prefrontal cortex in line with previous studies (Binder et al. 2005). The conjunction analysis revealed a common network comprising a set of areas including the left inferior parietal lobule bilaterally and frontal areas such as medial orbital–frontal cortex bilaterally and left frontal superior gyrus, which have previously been described as part of a general semantic system (Binder et al. 2009). We failed to observe activations in the ATL (see review in Jefferies, 2012). This is either because of signal loss and distortion which is typically observed in this area in functional MR studies that, as in the present case, do not adopt specific distortion-correction procedures (Binney et al. 2010). We did not optimize the scanner acquisition to detect signals in areas of BOLD dropout because doing so works against detecting signal in other areas of the brain and we did not want to limit this initial study to a specific region of interest. Alternatively, the lack of ATL activation may be due to the very strict selection criteria of our stimuli, even though this would speak against the common interpretation of the functional role of the ATL as a general semantic convergence zone (Patterson et al. 2007; Kiefer and Pulvermuller 2011).

In the direct contrast between abstract and concrete words, we found a main cluster of activation in rACC bilaterally, also referred as pregenual ACC (Palomero-Gallagher et al. 2008), an area considered to be part of the cortical network engaged in emotion processing of linguistic as well as nonlinguistic stimuli (e.g., Bush et al. 2000; Pessoa and Adolphs 2011; Tamietto and de Gelder 2010; Etkin et al. 2011; Kanske and Kotz 2011).

Within the ACC, a subdivision has been made between a more ventral portion (comprising pregenual ACC and subgenual ACC) and a more dorsal portion (further divided into anterior and posterior dACC, Vogt et al. 2003). These subdivisions are reflected in patterns of connectivity with ventral ACC strongly connected with core-emotion processing regions, in particular the basolateral complex of the amygdala (Beckmann et al. 2009) and projects to the periaqueductal grey and other autonomic nuclei involved in visceromotor control (Chiba et al. 2001). rACC has been linked to emotional processing, more specifically the assessment of emotional valence of external and internal stimuli (Phan et al. 2002) and more recently it has been argued that rACC has a regulatory role in processing of emotional stimuli (Etkin et al. 2011; Kanske and Kotz 2011). In particular, it has been suggested to exert a top-down regulatory action on the amygdala in the case of emotional conflict (Kanske and Kotz 2011).

We did not observe activations for abstract concepts in areas such as the superior ATL, orbito-frontal cortex, and the amygdala, which have been shown to play a role in emotional and social processing (Zahn et al. 2007). In contrast to the study by Zahn et al. (2007), however, many of our abstract stimuli, although emotional (e.g., *agony*, *horror*, *hunger* and *joy*), did not clearly involve social situations, With respect to the amygdala, in the specific task (lexical decision), emotional activation is unnecessary and possibly detrimental, leading to top-down negative regulation of this structure (e.g., Etkin et al. 2011).

In contrast with other studies, we did not observe the areas of greater activity for concrete than abstract words (e.g., Jessen et al. 2000; Wise et al. 2000; Fiebach and Friederici 2003; Giesbrecht et al. 2004; Noppeney and Price 2004; Binder et al. 2005; Fliessbach et al. 2006). This discrepancy is not surprising if these activations observed previously were due to differences in sensory–motor properties of the concrete and abstract words used. As discussed above, our items were matched for both imageability and mode of acquisition, thus the two types of words in the experiment were matched in terms of sensory–motor properties.

The Representation of Abstract Concepts: Verbal, Sensory–Motor, and/or Affective?

Abstract concepts have been argued to be represented in a predominantly verbal format by a number of researchers, as evidenced by greater engagement of language-processing networks. In particular, left inferior frontal gyrus (mainly pars orbitalis) and superior temporal sulcus were observed in studies contrasting abstract and concrete word processing or knowledge for sensory-motor versus verbal properties of concepts (Binder et al. 2009; Wang et al. 2010). In the previous literature, greater reliance on verbal information for abstract concepts was argued to come about as the primary format of representation for abstract concepts (verbal coding as opposed to both verbal and imagistic coding for concrete concepts, Paivio 2007); or impoverished network-type representation in verbal memory for abstract concepts leading to greater reliance on linguistic context (Schwanenflugel and Shoben 1983; Schwanenflugel 1991).

One interesting way to think about the greater reliance of abstract concepts on linguistic information is in terms of "mode of acquisition," operationalized as subjective ratings of whether specific concepts are learnt primarily via language or experience (Goldberg et al. 2007; Della Rosa et al. 2011). In our study, abstract and concrete words were matched for mode of acquisition, yet we observed differences between abstract and concrete concepts both in RTs as well as in the neural network involved in their processing. Thus, our results argue against an exclusive (or even primary) role of linguistic information in the representation of abstract knowledge.

Within an embodiment framework, it has been proposed that abstract concepts would be derived from concrete ones via a process of metaphorical extension. For example, the concept of "understanding" would be learnt and then represented as derived from metaphorical extension of the concept of "grasping an object" to the concept of "grasping a concept" (Lakoff and Johnson 1980, 1999; Gibbs 1994). Thus, linguistic context would also play an important role here in mediating the mapping between concrete and abstract domains. There is some evidence in the literature that supports such a hypothesis. For example, Glenberg et al. (2008) showed effector-specific fatigue effects for movement toward or away from the body both for sentences describing literal movement (e.g., "You give the computer to Mark") and for sentences describing abstract movement such as "You give the idea to Mark"). Boulenger et al. (2009) found somatotopic activation along the motor strip for both sentences in which an action verb was used literally or metaphorically (as in the example of "grasping" above). It is, however, unclear how abstract semantic representations derived via metaphorical extension (such as in "grasping a concept") may further link to abstract concepts closely matched in meaning (such as "understanding a concept"). Indeed, a recent study by Desai et al. (2011) showed that whereas the neural networks involved in processing literal (e.g., "grasping a chair") and metaphorical (e.g., "grasping a concept") meanings are largely overlapping, no such overlap is observed for tightly controlled sentences that use related abstract concepts (e.g., "understanding a concept"). Assuming that abstract concepts are at least partially embodied in our affective system provides an alternative account. Barsalou and Wiemer-Hastings (2005) also suggested that abstract concepts and word meanings are grounded in introspective states (mental and affective), supporting this claim with preliminary evidence based on detailed qualitative analyses of speaker generated features for 9 concepts (3 highly concrete; 3 highly abstract, and 3 intermediate). Our work goes beyond by providing first evidence for a more pervasive role of effect in processing abstract concepts.

Valence and Word Processing

Although affective associations (both valence and arousal) were not manipulated in our study, our follow-up analyses provide interesting observations concerning how these variables affect word processing. A first general result here is that hedonic valence (namely, distance from neutrality) but not linear valence or arousal modulated signal change anywhere in the word processing networks (see also Lewis et al. 2007). When assessing valence-dependent modulations for all words (both concrete and abstract), we found a network of areas including the inferior occipital gyrus extending to the fusiform and inferior temporal gyrus bilaterally and in the middle temporal gyri, angular gyrus, putamen, and insula in the left hemisphere (see Table 4). While some of these areas are traditionally considered part of emotional processing system, other areas highlighted here are part of visual processing system. The fact that they are modulated by valence is in line with hypotheses according to which visual areas play a role in the processing of emotion stimuli (Pessoa and Adolphs 2011). Thus, processing more highly valenced words appears to differentially engage the visual processing system, regardless of whether these words are concrete or abstract. A crucial difference between abstract and concrete words, as our study suggests, is that after controlling for confounding variables such as imageability, context availability, and mode of acquisition, the residual effect of higher valence for abstract versus concrete words determines a stronger activation for abstract words in the rACC. As we have discussed above, rACC plays a regulatory role in the processing of emotional stimuli. The analysis in which we considered separately abstract and concrete words reinforced this view, in showing a strong modulation of the rACC for abstract words, and only a weaker, i.e. at a more lenient statistical threshold, effect for concrete words in a left mid-orbitofrontal region located more ventrally than the abstract-specific rACC effect. In summary, our evidence is compatible with the view that the lexical–semantic processing of both abstract and concrete words engage the visual-processing system extending over occipital, temporal, and subcortical areas, but that the activation of this system extends only to the rACC in the case of more highly valenced abstract words.

Conclusions

We have provided here novel evidence of an important link between processing abstract concepts and emotion processing. When all other lexical and sublexical variables are controlled, abstract words are processed faster than concrete words and their processing engages rACC, an emotion-processing region. Likely, this is because abstract words have more affective associations than concrete words. These results provide us important theoretical constraints on how abstract concepts are represented in the brain and, moreover, they lead to novel predictions concerning acquisition. Our results indicate that affective, not just linguistic development, may be considered as precursors of the successful learning of abstract vocabulary. Thus, assuming that semantic representation is multidimensional including a variety of different types of information (like sensory–motor and linguistics), our work shows that emotional valence is yet an additional dimension of how humans represent meaning of especially abstract concepts.

Supplementary Material

Supplementary material can be found at: http://www.cercor.oxfordjournals.org/.

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Notes

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