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Semantic memory: Distinct neural representations for abstractness and valence

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ABSTRACT

The hypothesis that abstract words are grounded in emotion has been supported by behavioral research and corpus studies of English words. A recent neuroimaging study reported that a single brain region, the rostral anterior cingulate cortex (rACC), is responsive to abstract words, and is furthermore modulated by the emotional valence. This finding is surprising because the rACC is not commonly associated with semantic processing. It is possible that the effects observed were driven not by abstractness, but rather by valence, since the abstract words used in that study were significantly more emotional than the concrete words. We tested this hypothesis by presenting participants with words that were abstract/concrete, as well as emotionally valenced/neutral in a 2×2 factorial design. Activations to emotional words overlapped with both abstract and concrete activations throughout the brain. An ROI analysis revealed that the rACC was responsive to valence, not abstractness, when concreteness and valence unconfounded.

1. Introduction

1.1. Neural basis of abstract semantic knowledge

Concreteness is a critical organizing factor in semantic memory and recognition of the dichotomy between abstract and concrete concepts has a long history in psychology and philosophy (Locke, 1685). An extensive empirical literature supports this dichotomy. The "concreteness effect" – concrete concepts are easier to learn, use, recall and recognize – has been shown in a wide variety of tasks, in both patient groups and healthy populations (Bleasdale, 1987; Day, 1977; de Groot, 1989; Howell & Bryden, 1987; James, 1975; Kroll & Merves, 1986; Rubin, 1980; Whaley, 1978).

However attempts to localize neural differences between abstract and concrete concepts has proven difficult. Patients with specific cortical lesions who have acquired language deficits most commonly experience greater impairments with abstract words than concrete words, but the lesions associated with this deficit do not have a consistent localization (Coltheart, 1980; Goodglass, Hyde, & Blumstein, 1969; Katz & Goodglass, 1990; Martin & Saffran, 1992; Saffran & Martin, 1990). In contrast, only a small number of cases exist in which a reversal of the concreteness effect – a specific deficit for concrete words leaving abstract words intact – have been reported (reviewed by Bonner et al., 2009). Bonner et al. (2009) identified 11 patients with semantic dementia who exhibited the reversal of the concreteness effect, specifically with visual-based stimuli, and located their peak neurological degeneration to a portion of the ventral surface of the anterior temporal lobes. This region is commonly affected in semantic dementia, however the reversal of the concreteness effect is quite rare in these patients (Hoffman & Lambon Ralph, 2011).

Neuroimaging studies have also yielded inconsistent findings. For example, some neuroimaging studies have shown stark distinctions in regional activity throughout the brain for concrete and abstract concepts, with almost no overlap (Binder, Westbury, Mckiernan, Possing, & Medler, 2005; D'Esposito et al., 1997; Perani et al., 1999; Wise et al., 2000) while others have failed to identify any regional differences, with all activations completely overlapping (Beauregard et al., 1997; Fiebach & Friederici, 2003; Friederici, Opitz, & von Cramon, 2000; Kiehl et al., 1999; Noppeney & Price, 2004; Sabsevitz, Medler, Seidenberg, & Binder, 2005). In a recent meta-analysis of the neuroimaging literature Binder, Desai, Graves, and Conant (2009) reported that the left inferior frontal gyrus (IFG) and the anterior-most portion of the left superior temporal sulcus (STS) were consistently activated in processing or retrieving abstract knowledge (see also Wang, Conder, Blitzer, & Shinkareva, 2010). Although this finding is promising, it is important to note that there are large inconsistencies between individual studies thus it is difficult to identify cortical regions specific to processing abstract conceptual knowledge. One explanation for these dispa-

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rate findings is that important stimulus dimensions were not controlled in the tested abstract concepts, an issue that is discussed in the next section.

1.2. Concreteness, imageability and emotional valence

An important advancement in studying the representational foundations of abstract concepts is the idea that abstract concepts may be grounded, or embodied, in affective meaning. The *affective embodiment account* suggests that while concrete words are learned and understood through sensory-motor referents, abstract words are learned and understood through emotional referents, and that emotional valence is a key component of abstract conceptualization (Vigliocco, Meteyard, Andrews, & Kousta, 2009).

Proponents of the AEA insist that this prior research has overlooked a key confounding variable: imageability. Most research in this field covaries imageability with concreteness because these two variables are tightly linked, but it is important to note their distinctions. Imageability is typically defined as the ease to which a word can evoke a visual image, while concreteness typically refers to whether the concept itself is situated in time and space (see for example, Paivio, 1967). These variables are conceptually related and tightly correlated with each other (e.g. imageability can account for 72% of the variability in concreteness (Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011), but nevertheless, distinct. Kousta and colleagues demonstrated that when imageability is controlled between abstract and concrete words, the concreteness effect disappears and in fact, abstract words are processed more quickly than concrete words (Kousta et al., 2011).

On this evidence, the AEA is formed. This account suggests that three kinds of information contribute to semantic knowledge: sensorimotor, affective and linguistic (Vigliocco et al., 2009). What ultimately divides abstract words from concrete words is that abstract words are more dependent on affective and emotional information, and concrete words are more dependent upon sensorimotor information, and both rely on linguistic information to some degree. According to this model, imageability is related, but ultimately independent, and failure to control for imageability in studies of concreteness have led to inaccurate findings. Emotional valence, in this model, works as a function of abstractness and cannot be controlled without losing some essence of abstract meaning. The decision to control one variable, and not the other, has obvious implications for behavioral research, as demonstrated by the absence and so-called reversal of the concreteness effect found by Kousta et al. (2011). It also has implications for studying the neural representation of abstract concepts, described below.

1.3. Neuroimaging concreteness and valence in the anterior cingulate

In a recent study, subjects were asked to carry out a lexical decision task on abstract and concrete words while undergoing an fMRI scan (Vigliocco et al., 2013). The abstract and concrete words were tightly controlled on an impressive range of lexical and sublexical variables, including imageability. However, the abstract words were significantly more valenced than the concrete words, using a measure of hedonic valence that does not differentiate negativity from positivity. The results of a subtraction analysis indicated that recognition of abstract concepts was associated with activations in one region: the rostral anterior cingulate cortex (rACC). Within the rACC alone, BOLD activity was modulated by hedonic valence. The authors argue that this evinces that abstract concepts are grounded in affective experience while concrete concepts are grounded in sensory-motor experience and that this has a neurological basis.

An alternative explanation for this finding is that the rACC was responding to emotional valence rather than abstract concepts *per se*. There is sound evidence behind this explanation. The rostral and ventral aspects of the ACC are part of paralimbic cortex (Bush, Luu, & Posner, 2000), playing a specific role in social and emotional processes, such as monitoring behavioral expectations (Apps, Balsters, & Ramnani, 2012). Non-human primates with experimentally created lesions to this region show decreased social interaction and decreased preference for social information (Hadland, Rushworth, Gaffan, & Passingham, 2003; Rudebeck, Bannerman, & Rushworth, 2008; Rudebeck, Buckley, Walton, & Rushworth, 2006). Neuroimaging studies have reported activations in this region to a wide variety of social-emotional tasks and manipulations such as watching emotional films (Lane, Reiman, & Schwartz, 1998) or social cartoons (Castelli, Frith, Happe, & Frith, 2002; Castelli, Happe, Frith, & Frith, 2000). This region has been implicated in social anxiety and processing of emotional faces (Klumpp, Post, Angstadt, Fitzgerald, & Phan, 2013). Perhaps most tellingly, activations are even observed with more subtle manipulations of emotion, such as the contrast between emotional and neutral words. Whalen and colleagues scanned subjects while they performed an emotional Stroop task and reported that emotion words, but not neutral words, activated the ventral ACC (Whalen et al., 1998).

1.4. Goals of this study

This study had two goals. First, we examined whether abstract verbal stimuli activate cortical regions overlapping with those activated by emotional stimuli, while carefully controlling emotional valence across the abstract and concrete stimuli. Using a 2×2 (concreteness $\times$ emotional valence) design, we asked participants to think deeply about word meanings, and to answer semantically meaningful questions, while undergoing an MRI scan. We then used subtraction analyses to explore whether any shared cortical regions responded to abstract concepts and to emotionally valenced concepts. Second, we specifically tested whether the rACC, cited in previous research as being selectively sensitive to abstract concepts and modulated by valence, would respond to abstract words more than concrete, when valence is controlled. In other words, we tested whether the rACC responded to valence *regardless of concreteness*, which would refute the specific hypothesis that the rACC plays a role in abstract conceptual knowledge in addition to responding to emotional valence. Unlike previous neuroimaging studies cited in the two major reviews discussed in the introduction (Binder et al., 2009; Wang et al., 2010), our two independent factors of emotional context and concreteness allowed us to explore areas of neural overlap between abstract concepts and emotional concepts. Furthermore, our stimuli were matched on a much larger range of lexical and sublexical variables, as compared to neuroimaging studies that pre-date studies by Vigliocco et al. (2013).

2. Materials and methods

2.1. Participants

Nineteen young adults were recruited to participate through Temple University (11 female, mean age = 23 years). All participants were neurologically and psychologically healthy, native English speakers, and right handed.

2.2. Stimuli

Stimuli consist of 164 nouns collected from the MRC psycholinguistic database (Wilson, 1988). The words are either very abstract (concreteness <350, $n = 82$) or very concrete (concreteness >550, $n = 82$) and also vary along the dimension of imageability,