



The left inferior frontal gyrus: A neural crossroads between abstract and concrete knowledge



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ABSTRACT

Evidence from both neuropsychology and neuroimaging suggests that different types of information are necessary for representing and processing concrete and abstract word meanings. Both abstract and concrete concepts, however, conjointly rely on perceptual, verbal and contextual knowledge, with abstract concepts characterized by low values of imageability (IMG) (low sensory-motor grounding) and low context availability (CA) (more difficult to contextualize). Imaging studies supporting differences between abstract and concrete concepts show a greater recruitment of the left inferior frontal gyrus (LIFG) for abstract concepts, which has been attributed either to the representation of abstract-specific semantic knowledge or to the request for more executive control than in the case of concrete concepts. We conducted an fMRI study on 27 participants, using a lexical decision task involving both abstract and concrete words, whose IMG and CA values were explicitly modelled in separate parametric analyses. The LIFG was significantly more activated for abstract than for concrete words, and a conjunction analysis showed a common activation for words with low IMG or low CA only in the LIFG, in the same area reported for abstract words. A regional template map of brain activations was then traced for words with low IMG or low CA, and BOLD regional time-series were extracted and correlated with the specific LIFG neural activity elicited for abstract words. The regions associated to low IMG, which were functionally correlated with LIFG, were mainly in the left hemisphere, while those associated with low CA were in the right hemisphere. Finally, in order to reveal which LIFG-related network increased its connectivity with decreases of IMG or CA, we conducted generalized psychophysiological interaction analyses. The connectivity strength values extracted from each region connected with the LIFG were correlated with specific LIFG neural activity for abstract words, and a regression analysis was conducted to highlight which areas recruited by low IMG or low CA predicted the greater activation of the IFG for abstract concepts. Only the left middle temporal gyrus/angular gyrus, known to be involved in semantic processing, was a significant predictor of LIFG activity differentiating abstract from concrete words.

The results show that the abstract conceptual processing requires the interplay of multiple brain regions, necessary for both the intrinsic and extrinsic properties of abstract knowledge. The LIFG can be thus identified as the neural crossroads between different types of information equally necessary for representing processing and differentiating abstract concepts from concrete ones.

Introduction

When we think about a “dog” we will generally refer to it as being “concrete” on the basis of a great amount of external sensorial information. When we think about “justice”, instead, we generally refer to

internal sensory experience and linguistic information, which we define as being “abstract” (Vigliocco et al., 2009, 2013; Kousta et al., 2011). Both concrete and abstract word meanings, however, may rely jointly, despite differently, on all these kinds of information. The way in which we rely on different types of information for representing a dog (i.e., to

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bark, love for animals, is domestic) and justice (i.e., prison, law, to lie) still needs to be clarified.

According to Dual Coding Theory (Paivio, 1991) concrete concepts are supported by both perceptual and verbal knowledge, while abstract concepts rely only on verbal information. In contrast, the context availability theory (Schwanenflugel and Shoben, 1983) proposes that differences are due to the quantity and availability of contextual information, which is more readily available for concrete than abstract words.

These theoretical accounts have been translated operationally respectively in two constructs: imageability (IMG), which measures the difficulty/ease with which a word evokes a mental image (Paivio et al., 1968) and context availability (CA), which measures the difficulty/easy to think of a context for a word. Higher values of IMG are associated to sensory-motor information, mainly characterizing concrete words, while the meaning of abstract words is mediated mainly through language, resulting in a low value of IMG. In addition, it is generally easier to find a context for concrete words, while it is harder to generate a plausible context in which an abstract word can be represented (Schwanenflugel et al., 1988; Schwanenflugel and Shoben, 1983).

Under the assumptions of both Dual Code Theory and Context Availability Theory, imageability is defined as a semantic property of word representation. Both concrete and abstract word meanings are also bound to context, even though abstract words have less sensory context and should therefore be more reliant on the internal and linguistic contexts in which they appear.

If imageability can be assumed as an intrinsic semantic property, the difference between low and high imageable words depends on how the semantic representations are characterized within the semantic system (Paivio, 1986, 2010). If context availability can be thought instead as an extrinsic property of word meaning, the difference between concrete and abstract words will be influenced by differences in the way these representations depend more or less on context.

Imaging studies supporting differences between abstract and concrete words show, quite consistently, a greater activation of the left inferior frontal gyrus (IFG) for abstract than concrete concepts (Perani et al., 1999; Binder et al., 2005; Noppeney and Price, 2004; Fiebach and Friederici, 2004; Friederici et al., 2000; Jessen et al., 2000), see Table 1. Abstract concepts have been differently and interchangeably characterized on the basis of concreteness, imageability or context availability.

This consistent finding has been interpreted in different ways. Following the intimate link between language and abstract word representation postulated in the dual code theory, some researchers interpreted the IFG activation as reflecting the involvement in a verbal semantic network supporting abstract representations (Sabsevitz et al., 2005; Binder et al., 2009). In agreement with the context availability theory, the greater activation of the IFG for abstract concepts has been attributed to the greater executive control demands exerted by these stimuli, as their meanings depend more upon context and consequently require more regulation than concrete words (Hoffman et al., 2015; Fiebach and Friederici, 2004).

In this study, we aimed at unravelling the role of the left inferior frontal gyrus in the representation and processing of abstract concepts, in particular on the basis of different connections driven by different types of information (i.e., IMG and CA), all contributing in abstract concepts' representations and processing.

On the basis of previous evidence, we expect an involvement of the left IFG for abstract concepts more than concrete concepts (classified on the basis of concreteness scale), for less imageable words and for words with a lower context availability rating score. However, imageability and context availability tap into at least partially different aspects of semantic representations and processing, according to the above-mentioned theoretical accounts. We thus predicted that imageability and context availability may contribute differently to the representation and processing of abstract and concrete concepts, representing respectively their intrinsic and extrinsic underlying properties.

The LIFG region is engaged by multiple cognitive tasks (Liakakis

et al., 2011), and its activation may represent the shared tip of an iceberg, appearing in many studies but subtended by partially different functional activity patterns. In this case, we hypothesize that the characteristics of the intrinsic and extrinsic information (IMG and/or CA) necessary to represent and process word meaning may engage the LIFG differently.

Our main aim was to unravel the role of the IFG on the basis of different functional associations and connections driven by selected aspects of abstract representations (i.e., IMG and CA) in the context of a lexical decision task.

Translated in neural terms, first we want to observe which of the areas modulated by information pertaining to each of the two variables (i.e. the pattern of areas which create the informational basis for IMG and CA) is functionally correlated with brain activity in the area which responds significantly more for the distinction between what is abstract with respect to what is concrete. The assumption is that the information grounded in such areas is 'indirectly' responsive and tied to what we represent and categorize as abstract rather than concrete at a semantically higher hierarchical level. We used functional connectivity assuming that interregional correlations between LIFG abstract > concrete activity and different components of the IMG and CA circuits can detect a multimodal common informational grounding for "the representation of abstractness".

Our second objective was to establish in which areas sensitive to the information contained in the IMG or the CA parameter the BOLD signal is modulated by the "direct influence" of the IMG or CA on the BOLD signal in LIFG related to abstractness and necessary for processing abstract knowledge in a lexical decision task. We thus used an independent whole-brain psychophysiological interaction (PPI) analysis to assess context-dependent changes in the direct influence of one brain region on another.

Materials & methods

Subjects

27 right-handed native Italian speakers (mean age = 23.3 ± 2.60 years (range: 20–29 years) (8 males, 19 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. The study complied with all provisions of the Declaration of Helsinki and was approved by the San Raffaele Hospital Ethics Committee.

Stimuli

Thirty-five abstract (ABS) and 35 concrete (CNC) nouns were selected from Della Rosa et al. database (2010) on the basis of the median of the concreteness scale distribution (ABS mean = 331,34; CNC mean = 590, 83; $t = 17.27$ $p < .0001$), in order to be representative stimuli. We also verified that both imageability ($t = 12.23$ $p < .0001$) and context availability ($t = 5.59$ $p < .0001$) resulted significantly different. Abstract and concrete words were instead matched for other psycholinguistic variables known to affect abstract and concrete concepts processing, i.e. Mode of Acquisition ($t = -.037$ $p = .97$) (Della Rosa et al., 2010), Emotional Valence ($t = -.238$ $p = .81$) (Kousta et al., 2011; Vigliocco et al., 2013); Age of Acquisition ($t = -.267$ $p = .79$) (Cortese and Khanna, 2007), number of letters ($t = -.268$ $p = .789$), but not for familiarity ($t = 3.97$ $p < .0001$), see Table 2.

A total of 70 orthographically legal pseudowords were constructed from the word stimuli by randomly exchanging one or two letters (but not the initial letter) (Fiebach et al., 2002) with Random Word Generator (<https://www.gammadyne.com/rndword.htm>), which can extrapolate random pseudowords from a given word. The deviance from the original word was set to a maximum of two letters, randomly picked among consonants and vowels at any site within the word, excluding the initial and final letter. Alternative pseudowords were generated for each of the

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