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Relational vs. attributive interpretation of nominal compounds differentially engages angular gyrus and anterior temporal lobe

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ABSTRACT

The angular gyrus (AG) and anterior temporal lobe (ATL) have been found to respond to a number of tasks involving combinatorial processing. In this study, we investigate the conceptual combination of nominal compounds, and ask whether ATL/AG activity is modulated by the *type* of combinatorial operation applied to a nominal compound. We compare relational and attributive interpretations of nominal compounds and find that ATL and AG both discriminate these two types, but in distinct ways. While right AG demonstrated greater positive task-responsive activity for relational compounds, there was a greater negative deflection in the BOLD response in left AG for relational compounds. In left ATL, we found an earlier peak in subjects' BOLD response curves for attributive interpretations. In other words, we observed dissociations in both AG and ATL between relational and attributive nominal compounds, with regard to magnitude in the former and to timing in the latter. These findings expand on prior studies that posit roles for both AG and ATL in conceptual processing generally, and in conceptual combination specifically, by indicating possible functional specializations of these two regions within a larger conceptual knowledge network.

1. Introduction

Language's infinite generative capacity allows us to produce utterances ranging from the prosaic, as in "Close the door," to the ridiculous, as in "Hold the newsreader's nose squarely, waiter, or friendly milk will countermand my trousers" (Stephen Fry, *A Bit of Fry and Laurie*). Less ridiculous, but no less novel, sentences are uttered every day, and the ability of a reader or listener to understand such novel sentences, the propositional meanings of which cannot be retrieved from memory, requires a compositional algorithm that takes word meanings and combines them in such a way as to produce a more complex meaning. The neural substrates of this compositional algorithm remain elusive, in part because we still lack consensus on a typology of compositional operations.

Many approaches to the study of composition have benefitted from a clear distinction between syntactic and semantic composition (Kuperberg, Sitnikova, & Lakshmanan, 2008; Pylkkänen & McElree, 2006). Studies on Jabberwocky sentences demonstrate that subjects parse Jabberwocky phrases into syntactic hierarchical constituents similar to their natural language counterparts, even without knowing what the phrase means (e.g. "the mouse that eats our cheese" vs. the Jabberwocky version "the couse that rits our treeve" (example from Pallier, Devauchelle, & Dehaene, 2011)). Studies of complement coercion also suggest that syntactic and semantic argument structures are not isomorphic: evidence from behavioral, eye-tracking, and electrophysiological measures demonstrate a processing cost where semantic material unexpressed in the syntax must be inserted in order to coerce a coherent argument structure; e.g. "The man began the book" is interpreted as "The man began [reading/writing] the book" via implicit insertion of some event information (Baggio, Choma, van Lambalgen, & Hagoort, 2010; Kuperberg, Choi, Cohn, Paczynski, & Jackendoff, 2009; McElree, Pylkkänen, Pickering, & Traxler, 2006; Pylkkänen & McElree, 2007; Traxler, McElree, Williams, & Pickering, 2005).

In this study, we proceed one step further, and suggest that within the domain of semantic composition, there is evidence for a distinction between two basic combinatorial operations, *even when syntax is held constant*. Specifically, we investigate the case of noun-noun compounds, in which the structure is always a modifier noun followed by a head noun (e.g. *mountain lake*, where the syntax dictates this is a lake (in the mountains), not a mountain (in a lake)). Noun-noun compounds are a tractable case of minimal composition and are particularly interesting because the first noun – the modifier noun – can be either "attributive" (as in *zebra clam*, where *zebra* denotes the attribute "striped") or "relational" (as in *mountain lake* where "mountain" is not an attribute but an object

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bearing a spatial relation with "lake"). Attributive combinations are similar to predicating combinations, which can be paraphrased as "a [noun] that is [adjective]," such as *red ball* ("a ball that is red"). Non-predicating combinations, on the other hand, cannot be paraphrased in such a way: e.g. *tennis ball* is not "a ball that is tennis," but rather is "a ball for playing tennis" (Downing, 1977; Gagné & Shoben, 1997; Levi, 1978). Attributive noun-noun compounds can be paraphrased as "a [head noun] that is [modifier noun]-like", as in *zebra clam* – "a clam that is zebra-like" (likely "a clam that is striped"). Relational noun-noun compounds are more complex in that they are non-predicating, and derive their meaning from some extrinsic predicating relation (e.g. "a ball *for playing* tennis") (Levi, 1978; Murphy, 1990).

We find evidence that relational and attributive interpretations of noun compounds differentially engage two regions of the brain otherwise broadly implicated in semantic composition: the angular gyrus (AG) and the anterior temporal lobe (ATL). Below, we discuss how the distinction between relational and attributive combination may shed light on the functional differences between these two putative neural "hubs" of semantic composition.

1.1. A tale of two hubs: The angular gyrus and anterior temporal lobe

Mounting evidence suggests ATL and AG are involved in semantic processing, generally, and in semantic composition, specifically; however, only recently has there been effort to characterize their division of labor. Both have been characterized as "semantic hubs," owing to functional and anatomical patterns that are consistent with multimodal convergence (Binder & Desai, 2011; Lambon Ralph, 2014; Patterson, Nestor, & Rogers, 2007; Seghier, 2012). The ATL is uniquely situated at the end of a caudal-to-rostral stream of information processing feeding from primary sensory and motor areas and association cortex (Binder & Desai, 2011; Binder, Desai, Graves, & Conant, 2009; Binney, Parker, & Lambon Ralph, 2012; Felleman & Van Essen, 1991). Moving anteriorly along the temporal lobe, one finds a caudal-to-rostral hierarchy emerge as neuronal responses are more tuned to complex stimuli and more invariant to low-level sensory variation; such a hierarchy has been established along both visual (Felleman & Van Essen, 1991) and auditory (Rauschecker & Scott, 2009) streams. This "graded convergence" may provide a mechanism both for attributive feature combination and, in the limit, for maximally invariant amodal, abstract conceptual representations. The culmination of this graded convergence up the temporal lobe (Rauschecker & Scott, 2009; Stringer & Rolls, 2002) is a basal rostral region of ATL shown to have very limited extra-temporal connectivity and high intra-temporal connectivity (Binney et al., 2012). Such neuroanatomical sequestration may be conducive to representing abstract, modality-invariant semantics. Thus, ATL is a prime candidate for attributive semantic composition.

In one of the first studies investigating the neural correlates of minimal two-word composition, Baron, Thompson-Schill, Weber, and Osherson (2010) found evidence from fMRI pattern analyses that the left ATL subserved the combination of concepts such that the superimposition of individual patterns of the simplex concepts YOUNG and MAN (as represented by various face stimuli) reliably predicted the activation pattern for the complex concept YOUNG MAN. Consistent with this finding, a magnetoencephalography (MEG) study of visually presented two-word phrases comparing nouns in minimal compositional contexts (*red boat*) with nouns in non-compositional contexts (in which a non-word letter string was concatenated with a real word, e.g. *xkq boat*) found increased composition-related activity in left ATL (Bemis & Pylkkänen, 2011). There is a growing body of functional and tractographic studies to suggest that the representational unit of property-based composition in left ATL may be multimodal sensorimotor features, particularly visual concrete properties of object-concepts in more ventromedial regions of ATL, and possibly more abstract auditory-visual properties in more dorsolateral regions of ATL (Coutanche & Thompson-Schill, 2014; Hoffman, Binney, & Lambon Ralph, 2015), corroborating the notion of the left ATL as hub of the so-called ventral "what" pathway.

In addition to the ATL, researchers have also ascribed the label "semantic hub" to the AG, as it lies at the junction between temporal, parietal, and occipital lobes and thus receives a confluence of auditory, somatosensory, spatial, and visual inputs. Conceptual combination studies of the sort described above (Bemis & Pylkkänen, 2012) have demonstrated involvement of both left AG and left ATL, and several studies implicate bilateral AG in the contrast between well-formed sentences on the one hand and word lists, pseudowords, or scrambled sentences on the other (Bavelier et al., 1997; Bottini et al., 1994; Humphries, Binder, Medler, & Liebenthal, 2007; Humphries et al., 2006). AG also shows greater activity for semantic violations vs. congruent well-formed sentences (Kang, Constable, Gore, & Avrutin, 1999), particularly semantic incongruities violating verb-argument structure and thematic constraints rather than real-world knowledge (Kuperberg et al., 2008; Newman, Pancheva, Ozawa, Neville, & Ullman, 2001), and also for connected discourse vs. unrelated sentences (Fletcher et al., 1995; Homae, Yahata, & Sakai, 2003; Xu, Kemeny, Park, Frattali, & Braun, 2005). This broad profile of effects has led some to suggest that the AG may play a potentially domain-general role in semantic information integration structured around events.

Not all studies investigating conceptual combination find activation in both left ATL and bilateral AG. Of those stimuli that elicit differential activity in AG but not in left ATL, one finds that the type of composition may more often be based on thematic relations rather than attributive combination. Graves, Binder, Desai, Conant, and Seidenberg (2010) compared familiar meaningful noun-noun compounds, such as *lake house*, with reversed phrases, such as *house lake*, the meanings of which were not obvious; they found that right AG, along with other right-lateralized temporoparietal areas, showed greater activation for processing the more obviously combinatorial phrases. Interestingly, the authors noted that most of their noun-noun stimuli were interpreted as denoting thematic relations between head and modifier nouns; that is, most compounds consisted of nouns participating in some spatial relation (as in "*a house on a lake*") or event-based relation rather than picking out an attribute of the modifier noun. It is likely that these stimuli were probing semantic thematic relations in particular rather than combinatorial semantics in general.

1.2. Relational vs. attributive interpretation of nominal compounds

In order to further distinguish between property-based associations and relation-based associations between concepts, consider the following nominal compound: *robin hawk*. Wisniewski (1996) found that people's interpretations of a novel compound of this sort could be characterized in one of two ways. Some individuals applied a property of the concept "robin," such as a red breast, to the head noun "hawk," to arrive at an interpretation like "a red-breasted hawk." Others found a thematic relation between the two birds, noting that a hawk might hunt a robin, and interpreted "robin hawk" as "a hawk that preys on robins." In the first type of interpretation, "robin" indicated some attribute or feature commensurate with the head noun "hawk," while in the second type of interpretation, the modifier noun "robin" was not broken down into features, but rather participated in a thematic relation with the head noun "hawk."

It is worth noting here that the terminology "relational" and "attributive" bear the misfortune of being both very common and