The Royal Road to Semantic Cognition:
Untangling Semantic Components in Temporal Lobe

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An influential view on time and fate has it that the world is a complex system with diverse attractor states, implying that any life would find its way to wherever it ends up regardless of any particular event, thus rendering most thanks superfluous. An opposing tradition suggests that a person's whole future could turn on the most innocuous dime: a chance conversation at a café, an introduction made or missed. My temperament is more amenable to the latter, a tendency now strengthened by the post-defense salience of all the people who've seen me to this place.

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Dedication

To mom, for starting it.

To Monica, for enduring it.

Abstract

Functional magnetic resonance imaging (fMRI) research into semantic cognition has returned highly variable results, especially in anterior temporal regions. One likely reason for this variability is that tasks used to investigate this topic are believed to engage only shallow semantic processing. Another reason is that certain classes of stimuli (particularly abstract words) are often confounded by un-modeled social or emotional content; many researchers believe that it is this social and emotional information, rather than general semantic information per se, that elicits response in ATL. Our experiments use a task designed to elicit deep semantic processing (the triads task) along with explicit investigation into the social and emotional content of semantic stimuli to try to pry these factors apart and characterize the temporal lobes in general, and the ATLs in particular, with regard to their involvement in semantic cognition. We find that, contrary to some reports, the ATL is highly involved in semantic processing even in its most anterior aspects; that counter to prominent theories this involvement is not (or is not always) due to the inclusion of social or emotional content in the stimuli; and that a semantic task that engages deep semantic processing has an activation signature that closely resembles the signature of full-sentence processing, despite the seeming un-structured nature of the processing required by the triads task. We propose a general role for ATL as semantic integrator to characterize these disparate findings.

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Introduction

What is semantics?

For the purposes of this paper, semantics is the study of the mapping between words and the stores of knowledge a person acquires through experience.
We will use the term `concept' to mean the collective meaning of a thing that is denoted by a word. For instance, the word `apple' denotes the concept of a fruit the size of a baseball that is often red and sweet and that can be profitably baked into pies. For the sake of convenience we will sometimes use the words `word' and `concept' interchangeably, since at the level of our investigation they are for practical purposes synonymous.

It is reasonable to ask what, exactly, is included in a concept. For instance, does the concept denoted by `apple' include the fact that they can be thrown at people's heads? Or that if you run over one with your car it will make a crunching noise? To understand the sentence `George ate an apple' must the brain retrieve everything it knows about apples?

Achieving and articulating a better sense of what a "concept" is, and what happens neurally when we encounter concrete concepts such as "apple" or more abstract concepts such as "democracy" or "intangibility" is the purpose of the work we report here.

Semantic representations

Abstract and concrete defined

In empirical research, concrete words are generally taken to mean those words that have specific sensorimotor (SM) referents and are tangible in the real world. They can be distinguished from abstract words in a number of ways. Convergent research findings show that concrete concepts are more easily learned (Caramelli et al. 2004) and remembered (Begg & Paivio 1969) than are abstract concepts; and concrete language is processed more quickly (de Groot 1992.) Behavioral work by Hill and colleagues (2014) shows that concrete words are less entropic than are abstract words: concrete words have fewer, stronger associations with each other, and these associations are directional (Hill et al. 2014).

Abstract concepts, unlike concrete concepts, do not have tangible extensions in the real world and so are remote from direct perception (Shallice & Cooper 2013). Perhaps for this reason they have been much less studied than have concrete concepts (Recchia & Jones 2012; Wiemer-Hastings & Xu 2005). The theoretical accounts underlying abstract semantics are also less constrained, particularly with regard to embodiment issues, since for concepts that do not relate to perceivable phenomena it is not clear what would be embodied: as Pecher et al. (2011) point out, "[D]emocracy does not have a particular color, shape, smell, sound, or weight."

Features

A popular way to describe concrete concepts is as a set of quantitative ratings of their SM features — their colors, shapes, graspability, the sounds they make, etc. These feature ratings define a high-dimensional coordinate system in SM space that seems to have a neural reality reflected in the organization of concrete concepts. For instance, although the neural representations of concepts are distributed in the brain (Barsalou 1999; Damasio 1989; Huth et al. 2012; Ishai et al. 1999), within the ventral visual stream, the distance between neural representations of concrete objects corresponds to the distance between their locations in feature-space. This is consistent with theoretical accounts in which concrete conceptual representations are aggregates of features that co-locate based on similarity (Simmons & Barsalou 2003).

A host of empirical studies from vision research confirm that the neural representations of concrete objects cluster together based on feature similarity (Agrawal et al. 2014; Kiani et al. 2007; Kriegeskorte et al. 2008). Conceptual and perceptual representations are thought to be closely related, with category-specific conceptual deficits emerging after pathologies to perceptual regions (Martin 2007; Martin & Chao 2001). For instance, damage to regions of cortex involved in shape-processing produced recognition deficits when subjects were presented with animal stimuli (presumed to be defined more in terms of visual features) while leaving recognition of tool-stimuli (presumed to be defined more in terms of motor use) intact. Damage to dorsal regions necessary for hand manipulation (BA6) produced the opposite effect (Warrington & McCarthy 1987; Warrington & Shallice 1984).

Based on this and other evidence, conceptual representations are often believed to be neurally represented anterior to the perceptual feature clusters from which they arose (Thompson-Schill 2003) following a more general posterior-to-anterior representational gradient that moves from the perceptual to the conceptual (Damasio et al. 1989; Visser et al. 2012).

While abstract words don't have perceptual features as they are usually construed — for instance, what shape is love? What is the texture of conservatism? — some theorists emphasize the increased number of introspective and socially related features in abstract (relative to concrete) words (Barsalou 1999; Barsalou & Wiemer-Hastings 2005; Recchia & Jones 2012), or highlight the contribution of emotion to abstract concepts, essentially casting emotion as another kind of SM feature (Vigliocco et al. 2009). Crutch and colleagues (2013) proposed a class of abstract conceptual features that include *sensation, action, emotion, thought, social interaction, morality, time, space, quantity, and polarity*. They found that aphasic patients were similarly compromised on words with similar feature profiles. These formulations essentially treat abstract concepts in the same way as concrete concepts — the features might be different (for example, visual vs. emotional) but the idea of a concept characterized wholly or in part by its bundle of associated features is still the same.

Perhaps a more crucial distinction than that between their constituent features is that abstract concepts are also thought to be defined more in terms of their relationships to other concepts (Crutch et al. 2009; Crutch & Warrington, 2010; Gentner 1981). As Firth (1957) put it, "You shall know a word by the company that it keeps." This idea is operationalized in the field of computational linguistics by tabulating the co-occurrence statistics of words to other words, which, after some mathematical massaging, produces the definition of a word as either a point in high dimensional space (Landauer & Dumais, 1997; Landauer et al. 1998) or as a distribution over topics, which are themselves distributions over words (Blei 2012). In this formulation, abstract concepts would be grounded indirectly in physical reality via their linguistic relationships to concrete words (Harnad 1990).

While statistical formulations of word meaning can achieve impressive results in areas such as automatic text categorization (Griffiths & Steyvers, 2004) they leave a great deal unspecified about exactly how abstract concepts relate to other concepts, and what those relationships afford. Although the word ‘basketball’ and ‘point guard’ might co-occur with high frequency, knowing about the co-occurrence statistics tells you little about the mechanics of their interactions. Another family of theories addresses this deficiency by positing that relationships between abstract concepts are structured by the roles they fill for each other (Markman & Stilwell, 2001). For instance, the concept of ’employee’ isn’t defined by any particular set of features — rather, a person’s status as an employee is determined by her relationships to and participation in other conceptual constructs (an employer, a workplace, the exchange of money for labor) which are themselves hierarchical webs of roles and relationships.

Theorists have proposed a variety of ways to capture the information inherent in these relationships, for instance, by simulating interactions between entities (Barsalou & Wiemer Hastings 2005), via force dynamics (Talmy 1988), or through schemas (Mandler 2004), scripts (Schank & Abelson 1977), or metaphorical structure (Lakoff & Johnson 1980). However, there is little specific information about how and where these featural and relational aspects of abstract concepts would be neurally instantiated.

Neural representations

The myriad differences between concrete and abstract concepts suggest that they may be represented differently in the brain. An introduction by Binder (2007) summarizes a body of non-imaging research suggesting that processing concrete semantics recruits regions in both cerebral hemispheres. These results come from experiments where stimulus presentation is restricted to half the visual field of view (which results in information preferentially presented to a single hemisphere), from studies in patients with severed corpora collosa, and from electrophysiological experiments. Studies of patients with semantic dementia (Hoffman et al. 2013) provide converging results.

Evidence of this kind has engendered one of the venerable theories of semantic representation: the “dual code theory” (Paivio 1991) which proposes that more `imageable’ concepts — what we’d call concrete concepts, which exist in the world and can be imagined vividly — are represented using two distinct codes: a perceptual code defined by the bundle of SM features associated with the concept, assumed to be subserved by SM cortex bilaterally; and another code representing the concept’s web of linguistic associations, assumed to be subserved by left-hemisphere (LH) perisylvian language networks. Abstract concepts, on the other hand, are characterized chiefly (or solely) by the latter. Later theories adopted similar two-system distinctions with various refinements through which abstract concepts could be embodied (e.g., Andrews et al. 2009; Barsalou et al. 2008; Borghi et al. 2013). A competing view by Schwanenflugel (1991) posits that the distinction between abstract and concrete concepts lies in the amount of context associated with each. For instance, concrete concepts occur in real environments in relatively stable and predictable patterns, which means that summoning an appropriate context within which the word can be interpreted is easier, and that these contextual associates and the target concept will be mutually-reinforcing and are the source of the concrete advantage. Several studies show that when context availability is equalized, performance differences between the two classes disappear (Schwanenflugel & Shoben 1983; Schwanenflugel et al. 1992).

Despite these theoretically- and empirically-grounded considerations suggesting that concrete semantics are processed bilaterally, results from neuroimaging studies across fMRI and PET are inconsistent. In a review of studies investigating concrete and abstract semantics (Binder 2007), six of the fifteen studies showed no activation differences of any kind for concrete relative to abstract semantics. Of the nine that did show such a difference, four showed no RH involvement for concrete semantics. However, a later meta-analysis of many more studies, using much stricter admission criteria relating to imaging parameters, task stimuli, and the nature of the comparison condition (Binder et al. 2009) shows localized RH activation during concrete processing; the methodological rigor of this investigation, and its scope, are a strong vote in favor of both bilateral representation of concrete concepts, and distinct treatment in the processing/representation of concrete and abstract concepts.

The anterior temporal lobe

The locus of our semantic investigation includes the temporal lobe in general, but we have special interest in the most anterior portions of the temporal lobe, or the "anterior temporal lobe" (ATL). Our interest is motivated by the great variability in results when this region is imaged during semantic tasks, and by the diversity of the theoretical accounts which purport to explain those results, which has made it a functional and anatomical region of considerable debate over the last decade (Hickok & Poeppel 2007; Martin 2007; Olson et al. 2013; Patterson et al. 2007; Tranel 2006).

A difficulty in dealing with the ATL is that the term has multiple meanings in the literature. Papers that come from work with temporal lobe epilepsy (TLE) patients often use the term to refer to the temporal pole (Brodmann area 38) and its immediate environs, a common target for resection. Proponents of the semantic hub hypothesis often use the term more loosely to designate anatomical regions that are compromised in semantic dementia (SD), a condition that provides empirical motivation for their position, but which results in lesions that are diffuse and imprecise both spatially and temporally, since damage is dispersed unevenly over many regions, varies across subjects, and spreads as the disease progresses (Brambati et al. 2009; Desgranges et al 2007; Hodges & Patterson 2007).

A reasonable definition that does not depend on pathology might include the temporal pole, the anterior parts of perirhinal and entorhinal cortices, and the anterior parts of the fusiform, inferior, middle, and superior temporal gyri (Olson et al. 2013). We will use this definition when we use the term `ATL', the term `TP' to describe temporal pole, and more precise language when discussing particular sub-regions falling under the `ATL' canopy.

Variations in ATL results

Aside from the variability in nomenclature, the activation results of ostensibly similar studies apparently probing the neural correlates of semantic cognition and conceptual representation also vary widely. One simple example of this variability comes from a popular contrast between abstract and concrete semantics, a stalwart of the semantic imaging literature. Two recent meta-analyses (Binder et al. 2009; Wang et al. 2010) show abstract > concrete activation results consisting of a single island of activation in the LH TP and anterior superior temporal sulcus/gyrus (aSTS/STG). However, two studies using word stimuli found activation including both the LH TP to the middle of the TL, as well as a large region in temporal-parietal junction (Noppeney & Price 2004) even when stimuli were matched on a large number of lexical and sub-lexical features (Skipper & Olson 2014). Another study, also using word stimuli, activated a region in the STG/STS/MTG spanning the whole length of LH TL (Sabsevitz et al. 2005).

The results of neuroimaging studies to date also diverge on the much coarser scale, of whether concepts are represented in the left vs. right cerebral hemispheres. For instance, a prominent theory of semantic processing described in the last section (Paivio 1991) suggests that concrete concepts should be represented bilaterally in visual areas as well as in LH language networks, whereas abstract concepts should be restricted mostly or entirely to LH language networks. This seems easy enough to test; however, results are hugely inconsistent: while some studies show the expected effect for concrete words (D'Esposito et al. 1997; Fiebach & Friederici, 2004) other studies show no regions in either hemisphere that activate more to concrete than to abstract words (e.g., Friederici et al. 2000; Grossman et al. 2002; Kiehl et al., 1999; Pexman et al., 2007).

Imaging the ATL

One source of variability in these results is that the ATL is difficult to image using fMRI. The region is situated near transitions between bone and air, which cause magnetic field inhomogeneities when using standard gradient-echo pulse-sequences (Schmithorst et al. 2001; Weiskopf et al. 2006). The result is very low signal to noise ratios (SNR) in this region (Devlin et al. 2000, 2002) especially in ventral aspects at the culmination of the visual processing stream (Grill-Spector & Weiner 2014; Kravitz et al. 2013).

Possibly as a result of this, many fMRI studies have failed to show ATL activation in general semantic tasks (Simmons et al. 2009; see Visser et al. 2010b for a review). In contrast, studies using PET imaging, which is not subject to the same susceptibility artifacts, have consistently shown activation in ATL in a host of semantic tasks (e.g., Mummery et al. 1999; Noppeney & Price 2002a, 2002b; Rogers et al. 2006). The discrepancy between fMRI and PET results has led some researchers to claim that absence of results in ATL amounts to a `false negative' owing to physiological conditions that make the region hostile to fMRI investigation (Visser et al. 2010a).

The situation has improved with time. Newer fMRI imaging hardware, as well as refined spin-echo pulse sequences and distortion-corrected scanning protocols (Embleton et al. 2010) improve the SNR in compromised regions of ATL, and many recent fMRI results now do show activation in various anterior temporal regions to general semantic tasks (e.g., Binney et al. 2010; Coutanche & Thompson-Schill 2014; Hoffman et al. 2015; Mion et al. 2010; Robson et al. 2014).

However, while the aforementioned physiological and methodological issues cannot be denied, it is also undeniable that certain tasks using certain stimuli have consistently produced fMRI activations in spite of the challenges described above. For instance, experiments using full sentences as stimuli have consistently activated large extents of the TL, including the most anterior polar regions (Friederici et al. 2000; Friederici 2012; Humphries et al. 2006; see review by Mar 2011). Tasks using famous faces and landmarks have also reliably activated the TP (Damasio et al. 2004; Sugiura et al. 2006), as have stimuli featuring social information (e.g., Olson et al. 2007; reviewed in Olson et al. 2013 and Wong & Gallate 2012).

Taken together, the difficulties with imaging ATL, and the inconsistent results that fMRI imaging produces, suggest that perhaps ATL and TP are not involved in domain-general semantic processing, but are rather specialized for some particular semantic category.

Theories of anterior temporal lobe operation

Convergence/divergence zones and amodal hub

In recent years a rough consensus has arisen that contrary to traditional, purely-amodal theories (Fodor 1983; Jackendoff 2002) semantic representations are at least partially embodied (Barsalou 1999, 2008; Gallese & Lakoff 2005; Gibbs 2006; Pulvermüller 2013), which means that some of the same 'neural machinery' (e.g., in secondary association cortices) involved in perceiving an apple (i.e., parts of visual cortex that respond to the visual form of an apple; or parts of gustatory cortex responsible for processing its flavor) are also involved in the conceptual representation of `apple.' Of course, this rough consensus is still very rough: the parameters and limit of the involvement of sensorimotor (SM) regions in semantic processing is still very much an open question, with different researchers staking out varying positions on the gradient between strongly- and weakly-embodied (Binder & Desai 2011; Meteyard et al. 2012).

If the neural representation of cognition is embodied, and therefore distributed across modality-specific regions, how are the diverse representational components collected together to form a whole? The dominant view is that they come together in what have been called convergence/divergence zones (Barsalou 1999; Damasio 1989; Meyer & Damasio 2009). A CDZ acts as a Hebbian layer that unites the various modal (SM) components of a concept's representation into a co-activating bundle.

According to CDZ theories, a concept's information converges at multiple levels — features are first aggregated within-modality by modality-specific CDZs (for example, visual feature conjunctions that occur together in faces) and then CDZ representations built from these aggregated features are themselves aggregated by higher-order CDZs in heteromodal cortex (for example, mouth shapes and the corresponding vocalizations produced by those mouth shapes). In this hierarchical fashion CDZ representations both aggregate and span modalities, and serve as a mechanism for abstraction and pattern-completion.

This basic CDZ idea can also be extended to explain other findings. For instance, in their Conceptual Topography Theory, Simmons and Barsalou (2003) posit that the patterns of activation in CDZs are based on the similarity of sets of modal features they're aggregating, with the result that converged representations would be distributed into clusters sharing coactivated features. Results in line with this account are frequently reported in the ventral visual stream (Grill-Spector & Weiner 2014; Kiani et al. 2007; Kravitz et al. 2013; Martin 2007) as representations in that region of temporal lobe progress from predominantly perceptual to predominantly conceptual (Carlson et al. 2014b).

It's unclear how many CDZs there are, and of their extent (Reilley et al. 2014). A number of researchers describe a network of first-order CDZs located close to the modality-specific regions they serve (e.g., Damasio 1989; Simmons & Barsalou 2003; Thompson-Schill 2003). Other frequently proposed locations of CDZs are the middle temporal gyrus and the angular gyrus (Binder & Desai 2011; Bonner et al. 2013).

A topic of current interest in semantics research is whether the collective activity of SM regions is, in and of itself, sufficient for the business of semantic processing — if the concept for `apple' is simply a [partial] re-instantiation of the same neural systems in the same locations that were active during the original physical experience with an apple (Barsalou 1999) — or if these distributed and modal representations are re-represented in a form that has been stripped of modality-specific content.

Some researchers claim that purely distributed representations are not sufficient, and that an additional amodal layer is necessary for purposes of conceptual generalization (Lambon Ralph & Patterson 2008; Rogers et al. 2004, 2006). This would allow category exemplars that are widely distant in similarity space in terms of their perceptual features (whales and mice, for instance) to nonetheless be closely related in other ways (they are both mammals, sharing important conceptual features). Additionally, an amodal representation could serve as a shortcut to enable conceptual processing to unfold in a reduced fashion, without incurring the metabolic costs involved with instantiating the full distributed SM representation (Bonner & Price 2013). An amodal hub would be, in effect, a `master' CDZ that serves as the Rome through which all conceptual roads flow.

Assuming for a moment that there is an amodal hub, where exactly would it be? Probably the most popular and contentious proposed location for such an amodal hub is the temporal pole, whose candidacy is underwritten by a variety of evidence. The most compelling evidence comes from semantic dementia (SD), the temporal variety of fronto-temporal dementia (Snowden et al. 1989). In SD damage to the TL proceeds in rostral to caudal order, with the TP showing the earliest and most severe damage. As damage to TL worsens, subjects suffer devastating systematic impairment that affects all concepts regardless of whether the concept is probed using words, pictures, sounds, or any other access modality. Another justification comes from anatomical evidence. The TP is considered to lie at the culmination of an information convergence gradient (Damasio 1989; Visser et al. 2012) flowing in a posterior (perceptual) to anterior (conceptual) direction. Finally, TP receives connections from a variety of modal systems, and projects both to hippocampus and to frontal lobe regions (especially inferior frontal gyrus) that have been heavily implicated in semantic processing and language (Gloor 1997). TP seems ideally placed at a crucial waypoint between sensory, mnemonic, and executive structures (Ding et al. 2009; Fan et al. 2014; Insausti 2013; Lambon Ralph et al. 2009; Pascual et al. 2013), although not everyone agrees with this characterization (Martin et al. 2014).

It would seem that the question of TP's involvement could be easily verified; unfortunately this is not the case. While the lesion evidence (including damage from SD) is compelling, results from patient populations are confounded by the extent and variability of the hypometabolism and cellular atrophy in each individual case; and while it's agreed that areas proximate to TP are affected early and severely by SD, more distant regions are also affected, including posterior aspects of temporal lobe, extending nearly to occipital lobe, as well as into frontal cortex (Brambati et al. 2009; Desgranges et al 2007; Hodges & Patterson 2007).

More recent evidence from SD, fMRI, and repetitive transcranial magnetic stimulation (rTMS) places the amodal hub more ventrally and caudally. Visser & Lambon Ralph (2011) showed that ventral ATL regions responded to a semantic task in which healthy participants made a living/non-living response to stimuli across multiple modalities: auditory words, environmental sounds, and pictures. This finding confirms results from Mion and colleagues (2010) in which the damage to the same region (and only this region) in SD patients correlated inversely with semantic performance; and likewise closely aligns with results from Binney and colleagues (2010) in which a) SD patients showed significant tissue damage in the region, b) healthy subjects showed activation in this same region for a synonym judgment task, and c) performance in different healthy subjects was compromised when rTMS was applied there.

The social processing hypothesis

A number of findings propose that ATL, particularly temporal pole, plays a crucial role in social processing (Ross & Olson 2010). Since social information is also semantic (and, as developed later, perhaps also emotional) this is a refinement on the view that ATL is involved in domain-general semantic processing.

Evidence for ATL's role in dealing with social information comes first from anatomy. The ATLs are highly connected to diverse regions with known roles in social cognition, including the amygdala and hippocampus, and to frontal regions like orbito-frontal cortex and pre-frontal cortex (PFC) by a white-matter tract called the uncinate fasciculus (von der Heide et al. 2013). Interruptions to these semantic-emotive circuits have been documented in a number of pathologies involving serious disruptions of social processing in humans and non-human primates (Olson et al. 2007; Parsons et al. 2013) including prosopagnosia (Gainotti et al. 2003), autism (Poustka et al. 2012; Scherf et al. 2013) and psychopathy (Gibbs 1997; Harenski et al. 2010).

Another piece of evidence in favor of ATL's social role is that even before methodological advances improved the ability to get signal from the region in fMRI imaging (Visser et al. 2010a), fMRI studies using social stimuli would consistently find activation there. For example, Simmons & Martin (2009) found activation in polar MTG/STG to person stimuli (vs. stimuli depicting buildings or hammers); then, using resting-state connectivity, they further showed that the aforementioned region of maximal person-selective activation was functionally correlated with regions in the wider social-cognition network, as defined by Frith (2007). A broad range of social information and stimulus types can produce similar results (Olson et al. 2007; Ross & Olson 2010; Zahn et al. 2007), including engaging in activities such as reading about embarrassing scenarios (Burnett & Blakemore, 2009), watching video of fearful body reactions (Grezes et al. 2007) or animations of shapes whose movements suggest human interactions (Ross & Olson 2010), recognizing familiar faces (Damasio et al. 2004; Sugiura et al. 2006) and even the sound of two people walking (Saarela & Hari, 2008; see Wong & Gallate 2012 for a breakdown of different kinds of social stimuli used in other experiments).

The social-processing hypothesis has broader application than it might seem at first because even when an experiment is not purposefully designed to feature it, social information is implicit in many stimuli and can confound the intended stimulus classes if it is not controlled. For instance, abstract words are more often defined in terms of social experiences than are concrete words (Borghi et al. 2013; Recchia & Jones 2012). Famous faces and landmarks, which consistently activate ATL and TP (Damasio et al. 2004; Pourtois et al. 2005), often contain significant social associations either directly (faces) or indirectly (landmarks). Sentence stimuli, which consistently activate much of the superior and middle gyri of TL all the way to TP (Fedorenko & Thompson-Schill 2014; Mar 2011), frequently depict scenes about people interacting in social settings. In meta-analyses by Visser et al. (2010a, 2010b) ATL was preferentially activated by auditorily presented sentences vs. pictures, visually presented sentences, and written words. This could be, in part, because auditory sentences most closely approximate realistic social communication practices, where what is communicated originates from an obvious speaker. In fact, stimuli of this sort activate ATL/TP so robustly that they're used in pre-surgical planning to spare language areas during TL resection (Binder et al. 2011).

For these reasons and others (Olson et al. 2013; Wong & Gallete 2012) the case for ATL's role in social processing is compelling. Social-specialization would go a long way toward explaining both the inconsistent results obtained in many semantic tasks (since the social component of the stimuli is often un-modeled) as well as the wide range of seemingly disparate tasks that engage the region (since the stimuli used to investigate the condition of interest may vary systematically with regard to social content).

The role of emotion in semantic processing

While the evidence for the social-processing hypothesis is compelling, it's important to note that social information, too, is a confounded measure, since social semantics are inherently bound up in emotional considerations and connotations. The two can be difficult to untangle in both directions; in a meta-analysis Binder & Desai (2011) report 14 activations throughout temporal lobe due to an emotional manipulation, but many of the putatively emotional stimuli could be just as easily classified as social.

For instance, social concepts like *mother* and *friend* and *jealousy* are laden with affective content, as are words like *brave*, *adventurous*, and *courage,* which were used as social stimuli in pioneering work by Zahn and colleagues (2007, 2009). In tasks assessing attitudes about race (Gallate et al. 2011) or gender (Wong et al. 2012) the social evaluation is probably mixed together with an emotional component (Greenwald et al. 1998); and the classic Heider & Simmel experiment (1944; recreated in ATL imaging experiments in e.g. Olson et al. 2013) consists of shape animations whose movements elicit strong emotional reactions — one of Heider & Simmel's subjects described the larger triangle in the animation as `blinded by rage and frustration.' (Heider & Simmel, 1944; as reported by Kerr & Cohen, 2010).

Further, stimuli featuring information about conspecifics that could be described as social, but which do not contain an emotional component (or where the emotional component is more difficult to describe), often activate regions in more caudal parts of temporal lobe. In a series of findings reviewed by Allison and colleagues (2000), experiments that used stimuli of hand movement, body movements, lip-movements, and eye gaze activated temporal lobes robustly and bilaterally, but not in their anterior aspects. This evidence suggests both that a) the term `social information' is underconstrained, and b) when social information is divorced from affective content the activation it elicits moves outside of ATL.

In addition to the social-processing hypothesis, another organizing theory of ATL posits the region as crucial for access to, or representation of, unique entities, such as particular people, places, or landmarks (Grabowski et al. 2001; Drane et al. 2013; Tranel 2009). As we mentioned in the last section, many of these unique entities contain latent social information. But emotion is interwoven there too. For instance, in tasks involving the identification of famous faces (Sugiura et al. 2001) or names (Sugiura et al. 2006) one might find that, in addition to recognizing his picture or name, subjects may also have an emotional reaction to Brad Pitt — the idea of the man can be inextricably bound up with a host of physiological responses, including affective ones; and for many people landmarks like the Eiffel Tower or the Colosseum are bound up with significant emotional content.

The role proposed for emotional content in semantic representation is unevenly articulated in theoretical models. Recent models take affect into account by explicitly including an emotional component among the conceptual features (Binder 2011; Crutch et al. 2013; Vigliocco et al. 2009), although others believe the emotional component to be principally associated not with semantics, but rather with lexical aspects of word retrieval (Keuper et al. 2012), a position supported by superior performance in lexical decision tasks using stimuli with greater affective components (Kanske and Kotz 2007; Kousta et al. 2009).

Even when it is not modeled explicitly, emotion may help differentiate semantic classes. We have seen in an earlier section that abstract words are typically characterized by greater emotional association than are concrete words (Kousta et al. 2011; Vigliocco et al. 2009, 2014). Since abstract and concrete words manifest differently on a variety of behavioral and imaging measures (e.g., Hoffman et al. 2015), it's possible that the difference is due, at least in part, to un-modeled differences in emotional content between the two classes. For instance, the aforementioned study by Kousta et al. (2011) showed that when other features were equated between concrete and abstract words, the increased affective information in abstract words led to an inversion of the concreteness effect, so that abstract words have a reaction time processing advantage compared to concrete words; in a comparable imaging study, Vigliocco et al. (2014) showed that when abstract and concrete words were equated on all features including emotion, no abstract > concrete activations appeared in temporal lobe. Crutch and colleagues (2013) showed that an aphasic patient demonstrated similar performance on both abstract and concrete words with similar feature profiles, where 'emotion' was one of the feature ratings.

These findings support the idea that semantic features in general, and emotional content in particular, can invert or alter the customary behavioral and neural distinctions between abstract and concrete words.

One possibility for ATL's role in emotion processing is that TP mediates the relationship between semantic information and the emotional gloss, which in turn allows that information to regulate behavior. As described in the last section, connectivity analyses (Binney et al. 2012) and cytoarchitectonic investigation (Ding et al. 2009) show that all three polar convolutions in TP connect via the uncinate fasciculus (von der Heide et al. 2013, Kier et al. 2004) to frontal areas involved with emotional processing. For this reason, TP has been proposed as a kind of "way station" allowing semantic information to mix with valuation from regions involved in affective processing and regulation (Rolls 2000; Rubia 2011).

The intermingling of affective and semantic/mnemonic processes within the temporal pole offer evidence for the claim that the region subserves emotional processing generally, and that its irregular involvement in semantic conceptual processing tasks could in part be due to its responsiveness to these latent factors. The various social deficits that accompany damage to the region described in the last section would therefore be due to disrupted integration of emotional valuation into semantic and behavioral repertoires, rather than deficits in social processing per se (Gibbs 1997).

Exercising the system

Semantic variability and task type

Previous research investigating the semantic system has employed a variety of tasks, from lexical decision (determining whether the presented stimulus is a word or not) to story comprehension to picture recognition. Not all semantics tasks are created equal, however, and it's possible that the failure of some semantic studies to find activation in ATL was because the chosen `semantic' tasks were simply not very semantic. In other words, while simply reading words can produce a semantic response (Mummery et al. 1999) the response elicited by such tasks often will be weaker than in tasks that require a deeper elaboration of concept features (Wilson-Mendenhall et al. 2013). This semantic variability is intuitive in the context of everyday representation of abstract and concrete concepts. For instance, the `meaning' of the Apollo space mission was probably very different to the astronauts, the wives of astronauts, and to the head of the Congressional Budget Office, based on what the Apollo mission required, afforded, and portended in its consequences for each party (Barsalou 1999; Cisek & Kalaska 2010; Gibson 1979).

Task-based differences in the depth of meaning-related processing have been measured quantitatively. In a series of studies, LeBois and colleagues (2014) showed that congruency effects, a type of priming effect, were not universally bestowed in the course of processing but rather depended on task characteristics: in their spatial priming experiment subjects did not automatically obtain the expected performance boost (Brookshire et al., 2010) unless the spatial aspects of the stimuli were made salient to them beforehand. In another example, Taylor and colleagues (2012) showed that a base-level object identification task that depended on access to distinctive features (vs. shared features) could be performed more quickly with concepts having more distinctive properties; they further showed that the effect was reversed (in favor of concepts with many shared properties) when the task was changed such that it depended on access to shared properties. In other words, concepts were processed differently depending on whether their features were favorable to the task subjects were performing at the moment.

Complementary evidence suggests that the degree to which semantic representations appear embodied also depends on the importance of SM features to the task at hand. For instance, Kan and colleagues (2010) showed that fusiform gyrus (a region commonly activated in the processing of concrete words) activated during a property verification task, but did not activate when simple statistical lexical co-occurrence was sufficient to make the property-verification decision; and Sato and colleagues (2008) showed that processing verbs involving hand actions slowed button-press reaction times during a semantic decision task, but not during a lexical decision task. The proposed explanation was that a task that required a more thorough elaboration of the semantic features of the presented action verbs (the semantic decision task) would interfere with motor cortex recruitment for button-pushing, whereas a task that did not require such elaboration (the lexical decision task) would leave motor cortex unencumbered, and consequently lead to superior reaction times. It is noteworthy for both advocates of embodied cognition and task-specific semantics that in neither the semantic decision nor the lexical decision tasks did processing action verbs involving foot motion cause a reduction in button-press reaction times, adding evidence to the idea that SM recruitment is both sensitive to task demands and specific to the SM systems required to re-instantiate SM features of relevant concepts.

These and other experiments (Evans et al. 2012; Papeo et al. 2009; Raposo et al. 2009; Solomon & Barsalou 2004; Van Dam et al. 2012) show that the neural response of the semantic system is not simply latent in whatever stimuli it happens to be processing. Rather, the nature of semantic activation is adaptive, and depends crucially on the way in which the semantics will be put to use by the task at hand (Fairhall & Caramazza 2013) – in short, the fact that you can slip on a banana peel does not make the peel's slippery aspect one of a banana's prominent semantic features (Whitney et al. 2011a). The implication follows that the semantic processing your task elicits will most often be only as thorough/deep/extensive as the task requires.

The triads task

For this reason, we chose the triads task for our experiment, to maximize our chances of engaging 'deep' semantic processing. In the triads task subjects are shown word triads centered on the screen, in white text on a black background, with one word above a horizontal divider, and two words below. For example:

eel

----

worm snake

The subjects' task is to select the word below the divider that is most similar in meaning to the word above the divider. In this (difficult) example, the option that is most similar to `eel' is `snake.'

The triads task is a semantic decision that holds a laudable record in the cognitive neuroscience literature (e.g., Noppeny & Price 2004; Jefferies et al. 2009; Pobric et al. 2009; Sabsevitz et al. 2005; or essentially equivalent tasks like the 'quad' task from Binney at al. 2010) for producing activations in temporal polar regions that other tasks, like lexical decision, sometimes fail to reveal (Kiehl et al. 1999). It is also a task that: (a) can be adapted to require both relatively easy versus more difficult semantic comparisons by varying how close each of the alternatives are in meaning to the target word, and to one another, and (b) can be used with several different stimulus types, including not only abstract and concrete words, but also non-semantic stimuli that can provide a tight comparison control condition, thereby addressing concerns about baseline tasks that also involve semantic processing and so may result in the "subtraction" of the effects of interest in ATL (Visser et al. 2010b). Furthermore, although the "context" provided by the semantic similarity triad task -- including both the instructional focus on meaning and the provision of two specific word comparison stimuli -- is not as highly specified as might be the case were the words presented within the more ecologically valid context of a sentence, the triad task arguably provides greater context than would the presentation of single words in isolation. Thus, (c) to the extent that the triad task provides some, albeit limited, context for all words, across-condition differences in context availability (Schwanenflugel 1991) should be attenuated. In turn this may increase the likelihood that differences in activation that are observed across conditions, such as for abstract vs. concrete words, are more likely to reflect fundamental differences in their underlying semantic representation.

Selecting the best match for the words within a triad should (we hypothesized) require a thorough elaboration of the feature catalogue associated with a concept, and prevent 'short circuiting' the semantic process. Of course, short-circuiting is always possible, even with a task that elicits deep semantic processing (Kosslyn 1976; Solomon 1997). For instance, Solomon & Barsalou (2004) showed that in a property-verification task, statistical co-occurrence could stand in for deeper conceptual processing, so that verifying that 'yellow' is a property of 'lemon' would not activate the conceptual system in the same way as would verifying less standard properties; and sometimes co-occurrence can lead to erroneous semantic judgments, where a strong association between items (like car, bike, petrol) can mask their actual similarity relationship (Hill et al. 2014). The short-circuiting danger could manifest in the context of our experiment in that a triad (chipmunk, squirrel, goldfish) might require very little semantic processing, since chipmunks and squirrels co-occur in a common semantic context (furry rodents that live in trees in wooded areas) and so a subject presented with this triad would have little need to retrieve the various features of chipmunks, squirrels, and goldfish to make the determination. While co-occurrence statistics provide an important source of information in semantic organization (Andrews et al. 2009; Landauer & Dumais 1997) it's likely that this flavor of semantic processing would look very different, neurally speaking, from processing that does not allow such statistical shortcuts.

With respect to our experiment, these findings suggest that a triad must have a target that is closely-enough associated with the sample so as to elicit a correct answer, but not so closely associated that producing the answer can bypass the steps in semantic processing we are most interested in exploring. That said, to explore semantic processing across a range of conditions, we also included triads that varied in how closely each of the two alternatives matched the sample, thereby varying the difficulty of the semantic decision process.

Conclusions

The roles of both the TL in general and the ATL in particular in conceptual processing have been the source of much investigation and disagreement. We have created the series of experiments and analyses described in this document with this contentious history in mind. Using triads that vary on the abstract/concrete metric we examine the neural correlates of abstract vs. concrete semantic processing. By varying the amount of social and emotional information latent in abstract triads (as well as in another emotional task) we investigate the contribution of social and emotional information to ATL activity. We examine how varying the number of included modality specific (sensory-motor) features that constitute a concept in the triads task changes the extent of produced activation, and how triads that require more 'creative' interpretations (because there is no obvious association between any pair of words in the triad) drive the semantic system differently than do more 'standard' triads with an obvious best answer. In the course of these different tasks and contrasts we hope to help untangle some of the threads concerning the region's role in semantic cognition.

Methods and materials

We next describe the materials and methods for the three different tasks included in this experiment. All the tasks (triads, sentence localizer, and emotion localizer) use the same acquisition parameters, which are described first. Stimuli and analytical issues specific to each component are presented in their own sections. Additions or amendments to these general methodological descriptions are discussed in the methods section particular to each task or contrast.

General methods

Participants

20 subjects participated in our experiment. One subject withdrew from the experiment partway through the first session due to physical discomfort; this subject's data were not included in the analysis. All subjects were native English speakers and were paid for their participation.

The average age of the 19 included participants (11 female, 8 male) was 23 years (SD = 6.7); participants had an average of 15.79 years of formal education (SD = 1.78). All but one of the participants was right-handed. One of our participants was significantly older than the others; excluding this subject from the age/education statistical calculation, the average age of our participants was 21.1 years (SD = 1.28), with an average of 15.44 years of education (SD = .98).

fMRI procedure

Subjects performed the entire experimental battery twice, over the course of two scanning sessions in which the second session was separated from the first by at least a week. Each scanning session took just under an hour, and the acquisition procedure for both sessions was the same. In each session, after a short anatomical localizer, we acquired a high-resolution anatomical image, followed by four functional runs of our triads task; two functional runs of the sentence localizer; then a single functional run of the emotion localizer. We then acquired a field map for use in distortion correction.

Image acquisition (anatomical)

We acquired a high-resolution anatomical image (T1-MPRAGE, TR= 2.3 s, TE= 2.96 ms, FA = 9 deg, matrix size= 256 x 240 mm) for functional data registration and cross-subject spatial normalization.

Image acquisition (all functional data)

Echo planar images (EPI) were acquired (TR = 2 sec, TE = 25 ms, FA = 77 deg, matrix size 96 x 96 mm) using a gradient-echo (GE) protocol on a Siemens Trio 3.0T scanner (Siemens, Erlangen, Germany) with a 12-channel receive-only phased array RF `bird cage' head coil.

We acquired functional images at an oblique angle (mean 26.7 degrees across all subjects and sessions) roughly parallel to the long axis of the temporal lobe as reflected by the subject's position in the scanner. We sacrificed whole-brain coverage (typically losing coverage over a portion of superior parietal cortex) in order to focus on anterior temporal lobe, and to compensate for susceptibility artifacts in that region. All functional scans acquired 37 2.5mm interleaved axial slices, with no inter-slice gap.

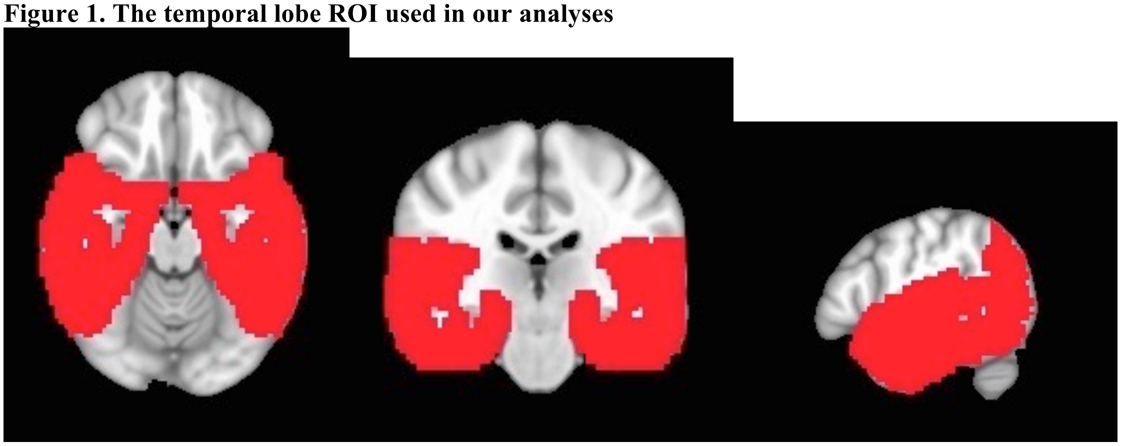
Image analysis (all functional data)

We used AFNI (Cox, 1996) for fMRI data analysis. The pre-processing and analytical pipeline proceeded according to AFNI's standardized analytical template, generated using the afni_proc.py script. For each participant, the processing steps included motion correction and distortion-correction (using a field map acquired at the end of every scanning session) with the FUGUE toolbox distributed with FSL (Jenkinson et al. 2012). Corrected images were then slice time corrected (using the first acquired slice as reference), spatially warped into standard MNI space, smoothed with a 4 mm FWHM Gaussian kernel, and normalized so that the resultant fMRI data was expressed in percentage signal change.

Analysis regions of interest (all tasks)

We used the AFNI (Cox 1996) 3dmask_tool program to create an anatomical region of interest (ROI) mask that combined the Brodmann areas in our temporal lobe region of interest, which included areas 20, 21, 22, 27, 28, 34, 35, 36, 37, 38, 39, 41, 42, covering (among others) temporal pole (TP), fusiform gyrus (FG), perirhinal cortex (PRC), parahippocampal gyrus (PHG), hippocampus (HPC), amygdala (AMY), middle temporal gyrus (MTG), superior temporal gyrus (STG) and ventral ATL (vATL) generally. Any gaps between the resulting masks ("grey-matter holes") were filled, and to compensate for variations in individual anatomy the mask was dilated 4 voxels in X,Y,Z. The resultant mask appears in the figure below, overlaid on a reference MNI anatomical brain.

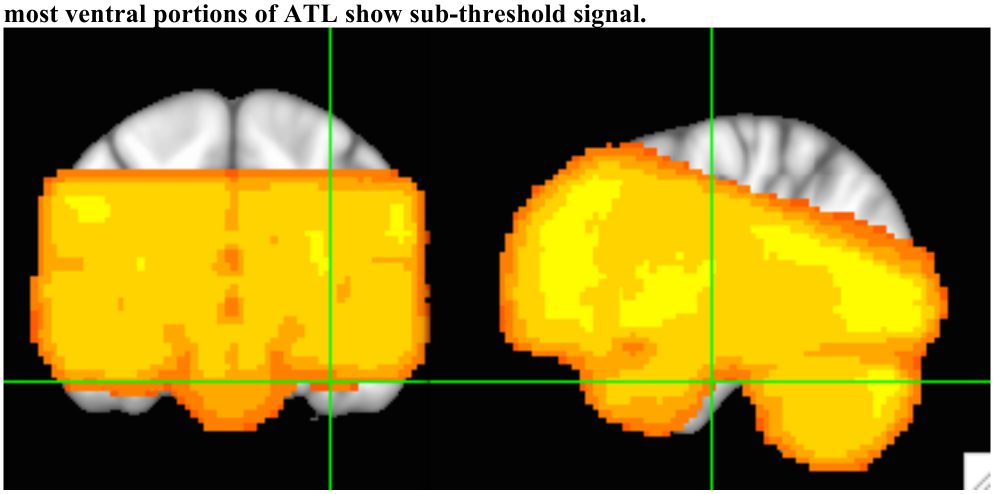
Figure 1. The temporal lobe ROI used in our analyses



Signal to noise of acquired data

As part of the standard AFNI processing pipeline, signal to noise (SNR) images were computed for each subject and session. We created a per-subject SNR by averaging the SNR results for each subject across both sessions (if both sessions were included in the analysis) or the single included session (in the event that a session was discarded for acquisition reasons). We then computed the average of these per-subject SNRs, which is shown in the following image. The image is thresholded at values greater than or equal to 40, in accordance with recent practice (Hoffman et al. 2015; Tyler et al. 2013), so that sub-threshold voxels appear grey.

Figure 2. Overall SNR of our functional data, overlaid over MNI reference volume. Some of the most ventral portions of ATL show sub-threshold signal.



We can see that SNR is good in all regions except for some portions of ventral ATL, consistent with physiological constraints that create imaging difficulties in that region (Devlin et al. 2000). The implications of these low-signal areas will be discussed in relevant sections.

Triads methods

Stimuli

The semantic triads in our experiment were compiled from several sources including original stimulus lists in published reports (Noppeney & Price, 2004) or provided to us by researchers (Jefferies et al., 2009; Sabsevitz et al., 2005; Whatmough et al., 2004). Additional possible stimuli, particularly for the single modality concrete triads, were generated by the investigators based on the modality exclusivity norms collected by Lynott and Connell (2009).

We used three types of semantic triads in our experiment. Concrete triads represent actual physical things or perceivable sensations. They are further subdivided into `concrete one modality' (COM) which are concrete items predominantly defined by a single sensory modality [HOWL, SIREN, CHIME] and `concrete natural multi' (CNM) which are items defined by a number of sensory modalities [LEOPARD, SCORPION, PANTHER].

Abstract triads represent items without direct sensory antecedents. They are further subdivided into `high social strength' (HSS) [RIVAL, ENEMY, GRACE] and `low social strength' (LSS) [REASON, FABLE, MOTIVE] items, as determined by a norming study. Note that the method of selection was to first choose abstract items, and only afterwards rate them in terms of high or low social strength. The implications of this choice will be discussed later.

Novel triads (NOV) are triads whose words cross the abstract and concrete categories; for instance, a novel triad might have two abstract words and one concrete word [CLINKING, HUMOR, RITUAL] or two concrete and one abstract [TASK, RABBIT, WHISTLE]. Novel triads were designed to have no correct answer, and participants were asked to find a meaning-related basis for selecting one over the other of the two provided options. Since there is no obvious way to match a sample (TASK) with a target (RABBIT or WHISTLE), we hypothesized that novel triads would exercise the semantic system most strongly of all triad types.

The triads task also included two non-semantic control conditions, x-letter triads (XLT), and number-word triads (NUM). In XLT triads, all of the stimuli were strings of x's, and participants were asked to select the alternative that was most similar in letter length to the sample. Triads from the XLT condition were not included in any subsequent analysis since the condition proved to be far easier (measured by reaction time) than every other triads condition. This difference in difficulty violated Binder and colleagues' (2009) admission criteria, which warned against under-constrained control tasks that could allow subjects to daydream or mind-wander. They hypothesized that daydreaming and mind-wandering could include un-modeled semantic activity that would then be subtracted away from the experimental semantic condition; this possibility was confirmed in a resting-state control condition by Binney and colleagues (2010), who went on to use a number task similar to ours (although with digits instead of words) as a more appropriate non-semantic control.

The number-words condition consists of triads of number words [TWENTY-TWO, FIFTY-EIGHT, TWENTY] for which participants were instructed to choose the number word that was closest in numerical magnitude to the sample word. The number-word condition is meant to be comparably difficult as the other triad types and to require largely the same processing steps (e.g., reading words, evaluating and selecting an appropriate word from two options) except without the semantic component.

Another important consideration in the choice of control task is also due to Binder et al's (2009) meta-analysis, wherein studies were not eligible for inclusion unless the difficulty of the non-semantic control task met or exceeded the difficulty of the semantic task under investigation. The purpose of this criterion was to avoid confounding putative semantic activations with difficulty effects owing to the increased cognitive load of the semantic (vs. the non-semantic) task. As will be seen from the behavioral results, our adherence to this standard is incomplete — the NUM triads are more difficult (measured by mean reaction time) than all other triad types except for the NOV triads.

We believe the potential confound of the response time differences for NOV vs. NUM triads to be minimal for two reasons. First, previous investigations (as well as our own results, discussed later) of the semantic system have shown that regions sensitive to task difficulty are largely independent of regions involved in the semantic task themselves (Binder et al. 2007; Binder et al. 2009; Duncan 2013); further, the regions that are most sensitive to task difficulty (pre-frontal regions) are not ROIs in the present investigation. Second, by explicitly including per-event reaction time in our subject-level model (as described below), at each voxel we absorb difficulty-related signal variance into a separate variable. The end result should be a semantic signal largely unpolluted by difficulty confounds.

Word features

To control for latent content in our triads we gathered word feature norms from the MRC psycholinguistic database (Coltheart 1981; Wilson 1988) which itself aggregates and curates word-feature data from a number of other sources. We attempted to select triads for our various conditions that were equated on features reported by the database that were not of interest in our investigation – written frequency, age of acquisition, numbers of letters and syllables, meaningfulness, familiarity – but this was not always possible. One difficulty was that coverage for these different features varied widely, and many feature ratings were not available for many words. Another, perhaps more important, difficulty was that meaningful semantic distinctions (such as between abstract and concrete words; or between one- and multi-modality concrete words) correlate with systematic distinctions in word features. Equating words from different classes (e.g., abstract and concrete) on large numbers of features tends to produce strange and atypical exemplars of those categories (see Skipper and Olson 2014 for a discussion). Since our investigation was principally concerned with the neural response to processing triads composed of words from different categories, we made no concerted effort to equate non-target features.

Two of the features reported in the MRC database that were of particular importance were concreteness and imageability, both of which vary systematically between words usually considered to be 'concrete' or 'abstract.' Concreteness and imageability norms were collected as a merger between the Paivio (Paivio et al. 1968), Colorado (Toglia and Battig 1978), and Gilhooly-Logie norms (Gilhooly and Logie 1980; see Coltheart 1981 for details of the merger). Concreteness ratings in this feature norm corpus range from 100 to 700 (min 158; max 670; mean 438; s.d. 120). Imageability ratings also range from 100 to 700 (min 129; max 669; mean 450; s.d. 108). Other norms we report in later sections include Kucera and Francis (1967) written frequency, which has poor coverage for our candidate words, and which varies from 0 to 69971 in the MRC corpus; and [printed] familiarity, combined from a variety of sources (Coltheart 1981) and ranging from 100 to 700 (mean 488, s.d. 99).

In addition to these off-the-shelf feature norms, our experiment is crucially concerned with emotional and social word features for which no or few existing corpora are generally available. This required us to collect our own norms for these features; that process is described next.

Affective norms

We gathered affective norm data for the 509 concrete and abstract words in our candidate stimulus set for which normative data was not already available in the Affective Norms for English Words [ANEW] database (Bradley & Lang 1999). Norms were gathered from 33 undergraduates at the University of Minnesota (mean age 21.7 years, 23 female). Subjects were given a sheet of paper with a task description, and a cartoon representation depicting a character manifesting nine quanta of valence and arousal taken from (Bradley & Lang 1999).

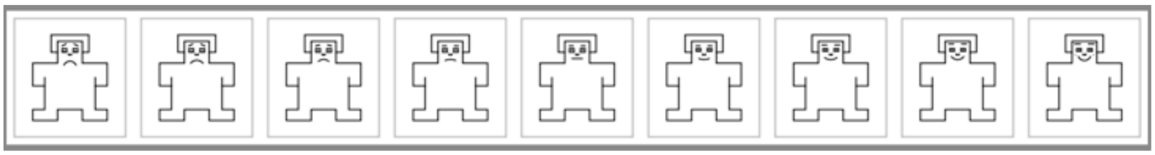


Figure 3. The nine quanta of valence, from (Bradley & Lang, 1999)

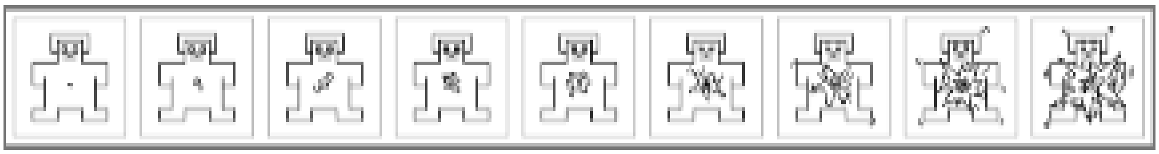


Figure 4. The nine quanta of arousal, from (Bradley & Lang 1999)

The norms were collected on a computer, with software written in Matlab, using the Psychophysics Toolbox extensions (Brainard, 1997). In the norming task, subjects were presented with a candidate word from the stimulus set (e.g., 'eel') and rated that word in terms of its emotional valence and arousal by typing a digit from 1 to 9, or 'x' if they did not know the word.

For valence, subjects typed 1 to indicate that the word had low valence (was 'strongly negative'), and 9 to indicate it had high valence (was 'strongly positive'); for arousal, a 1 indicated the word was not arousing (they were 'completely calm') and a 9 indicated it was highly arousing (they were 'completely agitated'). Our use of the re-descriptions for valence and arousal ('strongly negative', 'completely agitated') was motivated by early subjects' unfamiliarity with the terms 'valence' and 'arousal.'

The values for each word's valence and each word's arousal were averaged, except for subjects who did not understand the word, or whose response time for the word was more than two standard deviations away from the mean, in which case the subject's results for that word were omitted. The resultant word norms were then merged with the rest of the norms.

Social norms

We gathered social relevance norms for the 374 abstract words in our candidate stimulus set. Norms were gathered from 28 undergraduates at the University of Minnesota (mean age 20.6 years, 22 female). Subjects were presented with a candidate word from the stimulus set (e.g., 'advice') and rated that word on a scale from 1 to 5 in terms of 1) its strength of social connotation, and 2) the consistency with which the word is interpreted with respect to that social connotation.

To illustrate the difference between 'social connotation' and 'social consistency,' we can imagine that a subject might interpret the word 'aid' in two ways: an aid as a facilitator of something (a study aid, like a book, to help you learn Spanish), but also aid as the act of helping another person (like volunteering to help victims of the Haiti earthquake). Even if the second sense of 'aid' is highly social, the use of the word (in the subject's estimation) might be dominated by its first, non-social sense. Having the subject rate the words in terms of both social connotation and social consistency is designed to break these two apart.

The subject's ratings for the social strength and social consistency measures were ipsatized. The word's overall social strength and social consistency ratings were determined by taking the means of these per-subject ipsatized values. (The decision to ipsatize the social relevance norms was made in an attempt to account for differences in responder tendency. For instance, one subject may tend to avoid extreme judgments, such that her ratings are smoothly and normally distributed; in contrast, another subject may prefer the extremes, such that his ratings form a kurtotic, bi-modal distribution with peaks at both low and high values. Ipsatization, which amounts to standardization of a subject's responses with respect to herself, puts these two styles of responses into a common currency.) Stimuli were then classified into high social strength (HSS: mean ipsatized social strength, consistency = 0.35, 0.3) and low social strength (LSS: mean ipsatized social strength, consistency = -0.2, -0.2) groups by splitting on the median sum of these ipsatized values.

Task

Subjects were shown word triads centered on the screen, in white text on a black background, with one word above a horizontal divider, and two words below. For example:

Figure 5. Example CNM triad

eel

----

worm snake

Subjects were given an MR-safe button-box, and were instructed to select the word below the divider most similar in meaning to the word above the divider; to choose the word on the left, subjects pressed button 1; to choose the word on the right, they pressed button 2. Each triad in an experimental condition was on the screen for 4 seconds, regardless of when the button press occurred, though the onset of the trials could be irregular due to null-trial jitter, as described below.

Subjects were presented with four triad runs; each run was interrupted by a short pause, during which the scanner operator checked in with the subject over the intercom. During each run we presented the subject with 12 triads from each of 7 conditions (5 experimental semantic conditions: CNM COM HSS LSS NOV, and 2 non-semantic control conditions: NUM, XLT) for a total of 84 triad presentations per run. Each run also included 12 null fixation trials, for an overall total of 96 events per run. Trials for all conditions were 4 seconds long, except for the null fixation trials, which were jittered and had durations of between 2 and 6 seconds.

Trial types were presented in a pseudo-randomly intermixed order. The sequence of conditions in the event presentations was the same for all subjects. Events in the four runs were ordered based on the 4 most optimal event orderings, as determined by running the optseq2 program (Greve 2002) for a hundred-thousand iterations. For each subject, the candidate event stimuli were then mapped onto the event schedule for each of the four runs producing a custom event schedule for each run for each subject. The result is that while the order of per-event conditions was the same for all subjects, the ordering of exemplars drawn for the events of each condition was different for every subject and session. The presentation schedule for one subject/session appears in the appendix.

Behavioral results

As Figure 7 shows, subjects performed well on all triad classes, with per-condition accuracies ranging from 91% (CNM) to 96% (NOV – though note that for the NOV triads, any response received within the allotted time window counted as a correct response.)

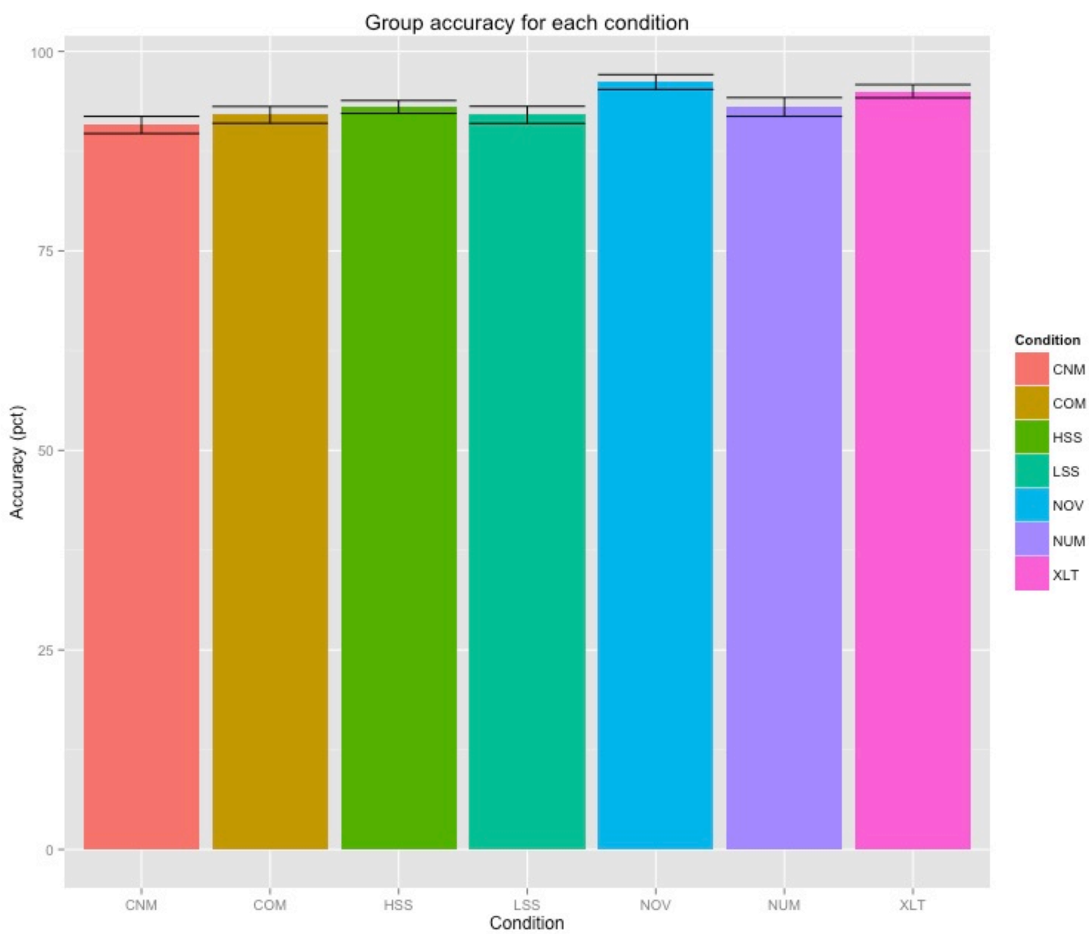


Figure 6. Per-condition accuracy across all subjects and sessions. Error bars represent 1 SEM.

The following figure gives a more detailed per-condition accuracy breakdown across all subjects. We note modest inter-subject variation, but also the general high level of accuracy across all subjects. (Also note the missing column, indicating the subject who was removed from the study due to illness.)

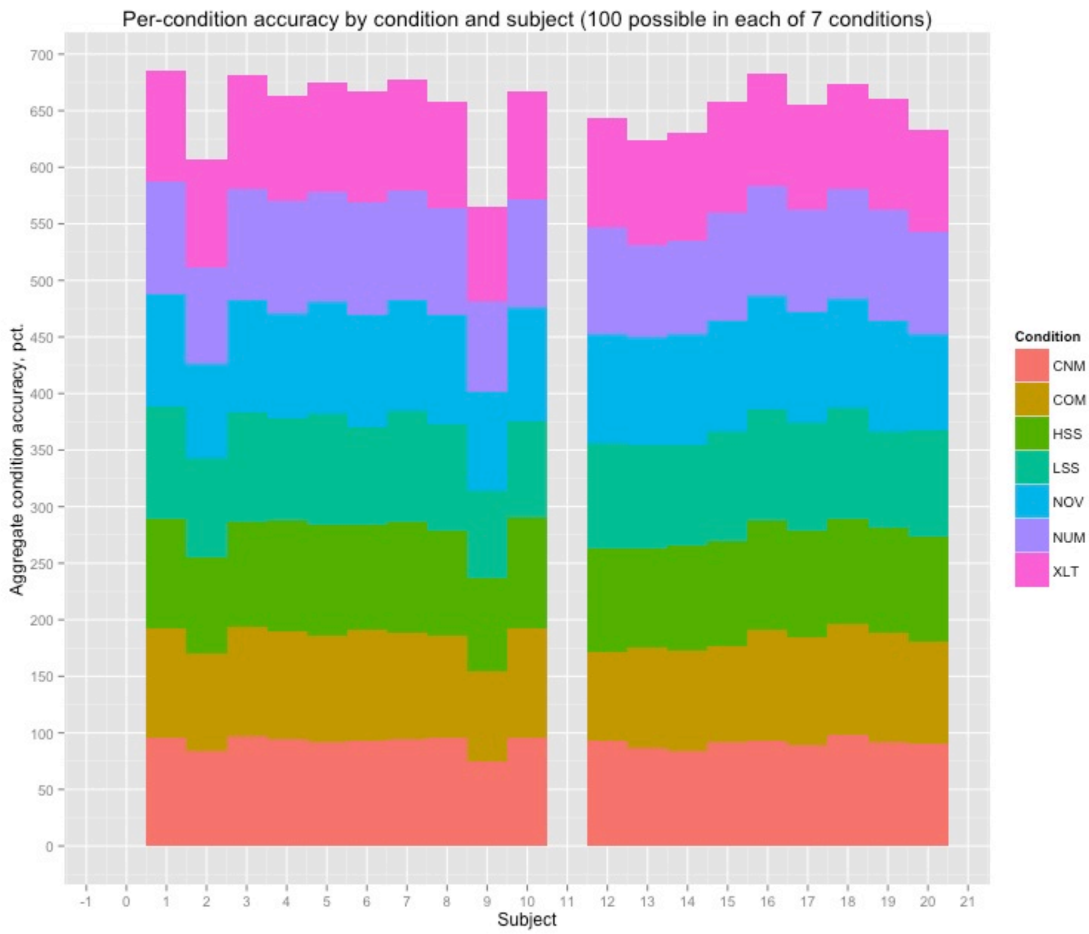


Figure 7. Per-condition accuracy broken down by subject. The blank column is due to the withdrawal of subject 11 due to illness.

The figure below shows the per-condition reaction times. Insofar as reaction time can be considered a proxy for difficulty, we can see that four of the five semantic conditions are comparably difficult, with only the NOV condition varying significantly from the others; and the non-semantic control condition used in the analyses described in the body of this document (the NUM condition) more difficult than all semantic conditions excepting only the novel triads.

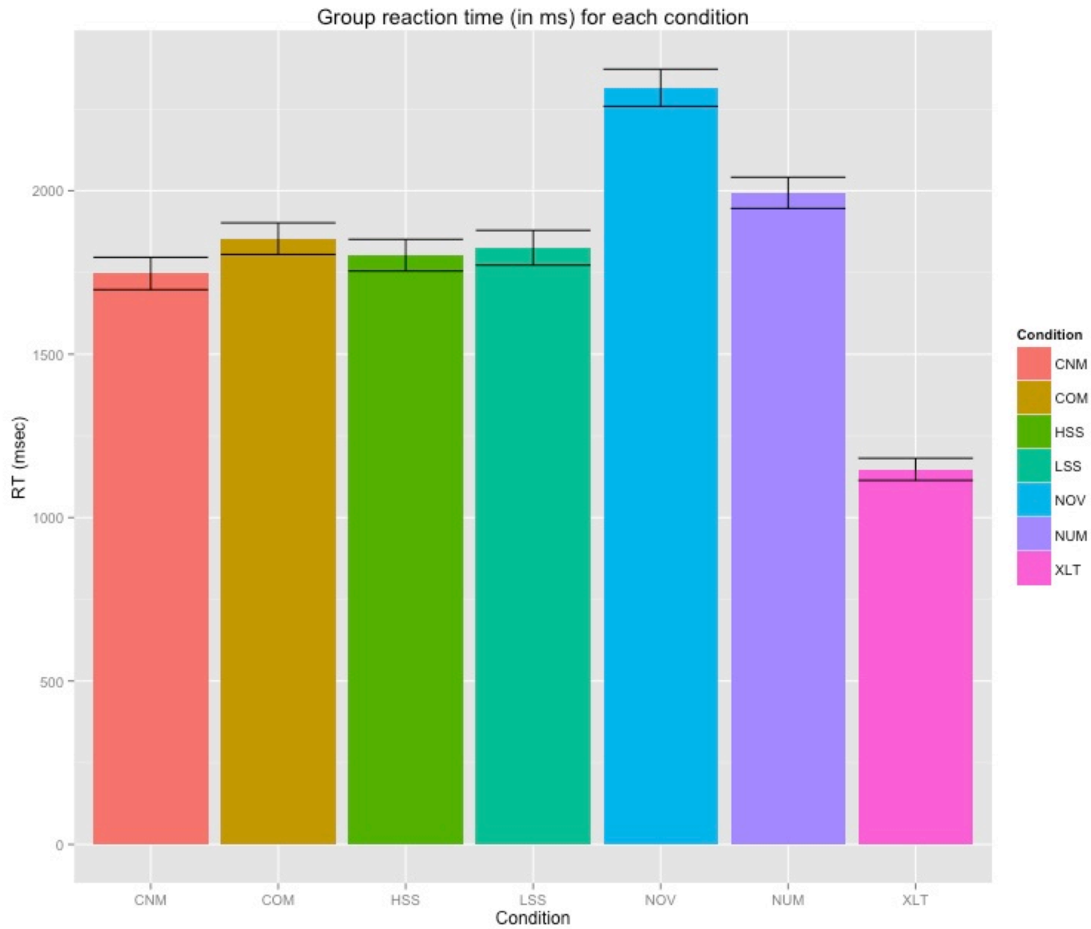


Figure 8. Per-condition reaction times (in ms) across all subjects and sessions. Error bars represent 1 SEM.

The following diagram drills down into per-condition reaction times for all subjects. Notable here is the varied reaction-time profiles demonstrated by different subjects. For instance, although subject 13 and subject 20 showed similar high accuracies across all triads conditions, their reaction times varied considerably. This variation will become important when we discuss the results of the emotion localizer task.

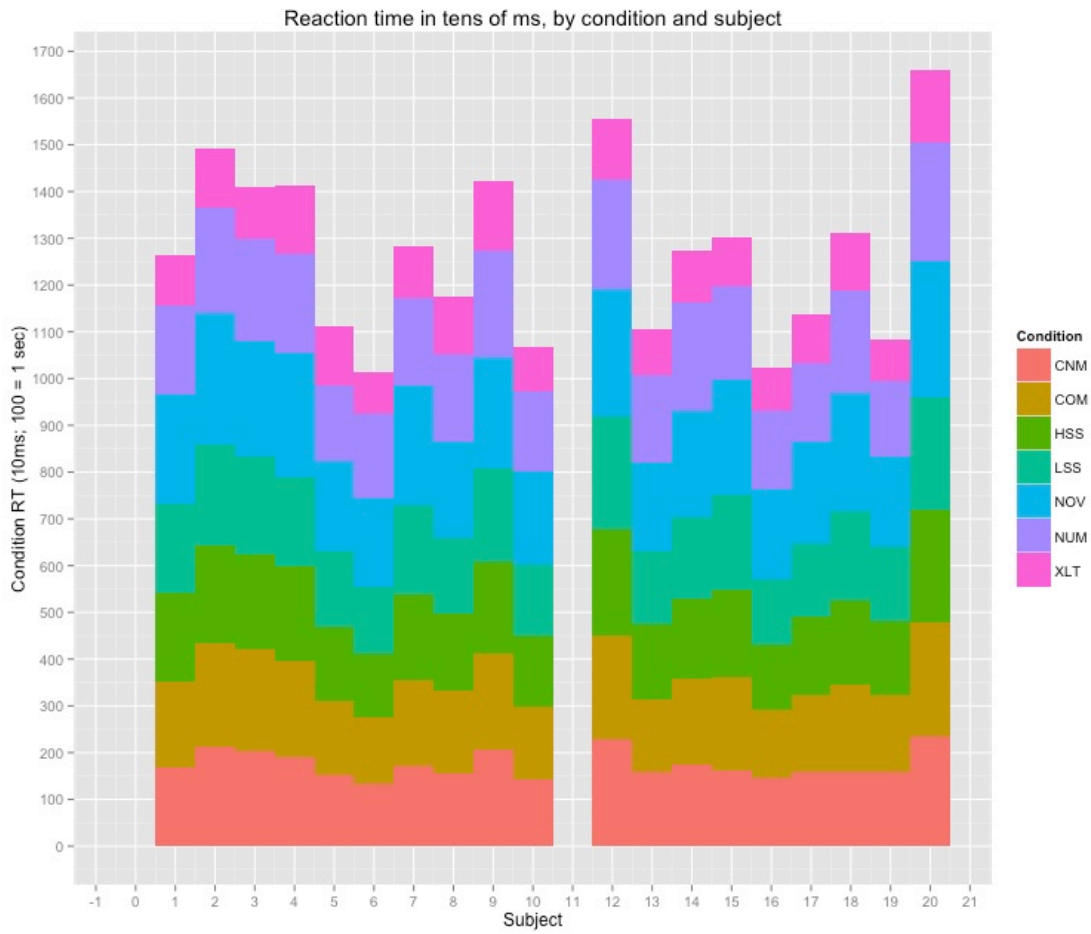


Figure 9. Per-condition reaction times broken down by subject.

Image analysis

After preprocessing as described in the general methods, the four triad runs of normalized functional data were then combined and fed as input to a general linear model. In a rapid event-related design, seven regressors of interest corresponding to events of each triad type (COM, CNM, HSS, LSS, NOV, NUM, XLT) were convolved with a block HRF with a four second window, amplitude-modulated by three parameters: reaction time, valence, and arousal in order to absorb per-trial variance related to per-event difficulty and stimulus emotionality. This amplitude-modulation resulted in 3 additional regressors to accompany each of the seven regressors of interest, and while for general purposes we can consider them to be nuisance regressors, in the course of the experiment we will sometimes examine them, or contrasts which include them, directly

— most notably, we will examine the voxels modulated by the valence and arousal parameters to see how latent emotionality would drive the semantic system were it not controlled.

Other nuisance variables are of no experimental interest and will not be discussed again: parameters corresponding to subject movement (translation in x,y,z and rotation in yaw, pitch, and roll), and those for constant, linear, quadratic, and cubic drift trends were also included in the model, which empirical work over a broad range of fMRI experiments has shown to characterize signal drifts in experimental runs comparable in duration to our own (Cox, 1996). Trial presentations which the subject answered incorrectly were not included in the model; and volumes whose acquisition was marred by head movement exceeding standard thresholds (0.3 mm) were censored.

The paradigm described above produced 2 statistical parameter maps per subject (one for each session.) These session maps were then averaged together for group analysis to produce the final aggregated maps for 18 of 19 subjects. Due to a problem setting scanner configuration parameters, one session's data for one subject was unusable, so instead of averaging the maps from that subject's two sessions, we instead used the map from the single good session for group analysis.

For our random-effects group analyses, we performed one-sample t-tests (vs. 0) on the difference between parameter estimates for conditions of interest (e.g., COM or HSS) minus estimates for the non-semantic control condition (NUM); or on the weighted aggregates of conditions minus control *(0.5 * HSS + 0.5 * LSS - NUM)* or vs. each other *((0.5 * HSS + 0.5 * LSS) - (0.5 * CNM + 0.5 * COM))*.

Unless otherwise specified, group-level tests were thresholded at per-voxel significance of $p < .001$, and cluster-wise significance of alpha < .01.

Searchlight methods

Image analysis

The result of the mass-univariate triad analysis described in the last section is that each of the non-NULL condition types (CNM, COM, HSS, LSS, NOV, NUM, XLT) is assigned a single value for each voxel in the ROI, so that the parameter value at each voxel corresponds to how much that condition (e.g., COM) modulates that voxel's activity, averaged across the 48 COM event presentations occurring across all four runs. This technique is unsatisfactory when analyzing data using multi-variate techniques, where what is desired is a set of training and testing samples corresponding to the events in each condition. For example, instead of a single per-voxel COM parameter value that represents how the typical COM condition modulates each voxel's activity, we would like 48 parameters per voxel per condition, which show how each of the 48 [COM, CNM, …] events modulate that voxel's activity. Having a larger set of labeled exemplars allows us to apply statistical and machine learning techniques that don't make sense with smaller amounts of data.

In certain block design experiments it can be feasible to extract per-block parameters for use with MVPA analysis using the usual GLM techniques (e.g., Haxby et al. 2001); the only difference between this and the normal univariate procedure is that different blocks for the same condition are not combined into a single condition-wide parameter, but are rather modeled individually, so that if there are six blocks for a certain condition (say, COM) in a run, instead of being combined into a single COM regressor, each COM block is modeled as a separate variable. Such a decomposition achieves a larger number of more granular parameter estimates (6 COM events are produced, instead of 1) but foregoes the leverage advantage in attributing all blocks of a particular condition to the same regression parameter.

One can use a similar idea called LSS-IM (least-squares separate, individually-modulated — Mumford et al. 2012; Turner et al. 2012) to retrieve a separate parameter estimate for each event in a rapid event-related design. LSS-IM uses data created from the same distortion-correction and pre-processing steps described in the univariate triads methods, omitting only the 4 mm smoothing step in accordance with standard practice for MVPA analysis (Norman et al. 2006).

Next, design matrices are created for each of the events; in our case, for the triads experiment, this means a design matrix for each of the 7 * 12 * 4 = 336 events, where 7 is the number of non-null conditions (COM, CNM, …) and 12 is the number of events per condition per run, and 4 is the number of runs. Each of the 336 design matrices models a single individually-modulated (IM) parameter corresponding to the current "focal" event of interest; and 7 nuisance regressors consisting of a) 6 parameters corresponding to all 48 events in the 6 other condition types, plus b) a parameter covering the 47 non-focal events in the current condition.

To illustrate this idea, the design matrix for the twentieth COM event would include 6 regressors for all non-NULL conditions other than COM (CNM, HSS, LSS, NOV, NUM, XLT). Each of these six regressors models the event onset for all 48 events convolved with a block HRF, exactly as in the univariate methods described in the last section. The difference is that in LSS-SN these non-focal conditions are variables of no interest. Similarly, the non-focal COM events (all COM events apart from the twentieth) are also convolved with a block HRF in the standard fashion, and also treated as a single nuisance variable reflecting non-focal COM events 1..19, and 21..48. It is only the twentieth COM event that is held out, so that the BOLD activity corresponding to this event can be `siphoned off' into the IM parameter.

The result of running the GLM on each of these 336 design matrices is a single per-voxel IM parameter estimate corresponding to each of the events across all 7 non-NULL conditions. The BOLD contributions of neighboring events, which overlap the BOLD response from the IM event due to the rapid event presentation schedule and the hemodynamic delay, are untangled with maximal leverage, since the full catalogue of events at all time points is used to estimate the nuisance variables. (The downside to this disentangling is that it requires 336 times as many computational resources for the regression step.) This leaves us with 336 per-voxel parameter estimates that can then be used as training and testing data in multi-variate classification. Since we have a set of 336 beta-images for each of our two sessions, the two sets are averaged together, just as they are in the univariate analysis described in the last section.

The MVPA classification scheme we used is an information searchlight (Kriegeskorte et al. 2006) procedure with a 3-voxel radius. In this searchlight process, implemented using the PyMVPA software package (Hanke et al. 2009), the classification performance between two conditions of interest is assessed at each voxel, using a vector of neighboring voxels as input. For instance, to determine voxel A's (VA) classification performance in distinguishing the COM vs. CNM conditions, a 3-voxel neighborhood around VA is identified, and a classifier is trained using as training data the vector of values of that neighborhood during some number of COM events, vs. the vector of values of that neighborhood during some number of CNM events. Performance is then assessed by examining the classification ability of that same voxel neighborhood during some number of COM and CNM events that the classifier has not yet seen.

The `some number' of training/test events are chosen, and performance is assessed, using leave-one-run-out (LORO) cross validation (Hastie et al. 2009). In this procedure, the data is partitioned into 4 training/test sets, where the training sets consists of events drawn from three runs (e.g., runs 1,2,3), and the test set consists of events from the remaining run (e.g., run 4). In an experiment with 4 runs, there are 4 permutations of this scheme. Performance is computed by taking the average classifier performance of training/testing on each of these 4 permutations.

The output of the entire searchlight process is a per-subject classification accuracy image (CAI), analogous to a beta image, in which every voxel in our cortical ROI contained the classification accuracy of the set of voxels within a 3-voxel radius. For our random-effects group analyses, we performed one-sample t-tests (vs. 0.5) on the collection of CAIs.

Sentence methods

Stimuli

The sentence localizer presented the subjects with blocks featuring collections of words or pronounceable non-words designed to have similar letter distributions as English words. Each block contained one of 2 types of stimuli: sentences, or `jabberwocky' sentences, which are sentence-like constructs except with content words replaced by pronounceable non-words. (For ease of reference we will refer to the groups of words in the sentence and the jabberwocky conditions as `collections' and the words/pronounceable non-words as `items'.) The task and stimuli were a subset of those used for language localization in (Fedorenko et al. 2010).

Task

Subjects performed two runs of the sentence localizer during each session. In each run subjects were presented with 12 blocks, containing 6 blocks of sentence stimuli and 6 blocks of jabberwocky stimuli. Each block began with a 16 second fixation. After the fixation, each block presented 5 collections of eight items: either real sentences (THE DOG CHASED THE CAT ALL DAY LONG) or jabberwocky sentences (INCORMED RALMING CRE EMTO SMASP OMOULT MINTER TEWLAIRE). Each item in the collection was shown on the screen for 350 msec. After all 8 items were presented there was a 300 ms fixation, and then the subject was shown two items and was required to select (by button press) which of the two items had appeared in the previous sequence of 8 items. The two options remained on-screen for 1700 ms, even after the subject selected a response. The total block length was therefore 40 seconds. Block types were counter-balanced, and the order of blocks was the same for all subjects.

Behavioral results

Taken across both sessions, accuracy across all subjects was 96% for the sentence condition, and 79% for the jabberwocky condition. For the trials in which subjects responded accurately, mean reaction time for the sentence condition was 725 milliseconds; mean reaction time for the jabberwocky condition was 834 milliseconds.

Image analysis

Pre-processing occurred as described in the general methods. The two runs of the normalized sentence localizer data were then combined and used as input to a general linear model. In a block design, two regressors of interest corresponding to events of each block type (SENT, JABBER) were convolved with a block HRF with a twenty-four second window (corresponding to the non-fixation component of the block). Nuisance parameters were included and censorship was implemented as in the triads task. This resulted in 2 statistical parameter maps per subject (one for each session.) These session maps were then averaged together for group analysis to produce the final aggregated maps, except for one subject where problems with data acquisition resulted in corruption of a single session's data. For this subject we used the map produced using the non-corrupted session's data.

For our random-effects group analyses, we performed one-sample t-tests (vs. 0) on the difference between parameter estimates for the SENT block vs. the JABBER block in the aggregate maps. We performed group-level tests at voxel-wise $p < 0.001$, and cluster-wise significance of clusters of at least 20 contiguous voxels for an alpha < .01.

Emotion localizer methods

As the emotional localizer is used in close concert with our abstract triads task, we will defer the description of its methods to the following chapter, which covers abstract triads.

Anatomical abbreviations

Abbreviations for anatomical structures in tables and in subsequent discussions are as follows:

Table 1. Anatomical abbreviations

Abbreviation	Structure
AMY	amygdala
FG	fusiform gyrus
HschG	Heschl's gyrus
HPC	hippocampus
INS	insula
ITG	inferior temporal gyrus
MedTG	medial temporal gyrus
MedTP	medial temporal pole
MTG	middle temporal gyrus
PHG	parahippocampal gyrus
SMG	supramarginal gyrus
STG	superior temporal gyrus
STS	superior temporal sulcus
TP	temporal pole

Abstract triads

Overview

While the functions that an abstract conceptual system must support are generally agreed upon, little is known about the realization of those functions in a neural architecture. In fact, as with concrete semantics, even empirical efforts using quite coarse characterizations of the abstract semantic system have produced widely varying results. As reported by two extensive meta-analyses (Binder et al. 2009; Wang et al. 2010) some studies have shown no difference in the apparent neural correlates of abstract vs. concrete semantics; while others have shown strongly lateralized differences; and yet others have shown bilateral activation.

Therefore, to establish an initial broad outline we will first contrast our abstract triads (which are divided into high- and low-social strength sub-conditions) vs. number-word triads. This contrast (abbreviated as ABS>NUM in the following text) will provide a general orientation to abstract semantic processing that will be refined in subsequent sections. By contrasting the abstract triads with number-word triads, and doing the same with the concrete triads, we will be able to see not only how the two conditions differ, but also what they have in common.

Of the 18 studies in Binder's meta-analysis featuring abstract semantics, only 2 showed results for an abstract vs. non-semantic contrast (Binder et al. 2005), or show the correlation of the brain activation with stimulus imageability or stimulus concreteness, by which a comparable measure can be constructed (Whatmough et al. 2004, Wise et al. 2000). We identified 2 additional studies not included in the meta-analysis that include this contrast (Kiehl et al. 1999, Skipper & Olson 2014). The results from these collective studies are, as one might expect, hugely variable. Insofar as there is activation in common, it occurs in the anterior part of STG.

Additionally, though it is not an "apples to apples" comparison, we can also draw from the more frequently examined ABS>CONC contrast results from the literature to motivate predictions for our experiment. The ABS>CONC contrast is likely to be considerably more conservative than the ABS>NUM contrast (since the former is subtracting away voxels involved in semantic processing, while the latter is not). We should therefore expect our ABS>NUM contrast to be a superset of any ABS>CONC activation. Using this logic, we will additionally predict further anterior activation of LH STG/STS, all the way into TP, based on the ABS>CONC meta-analytic results described above.

Results

Figure 10. ABS>NUM, (warm colors) and ABS<NUM (cool colors) LH to RH

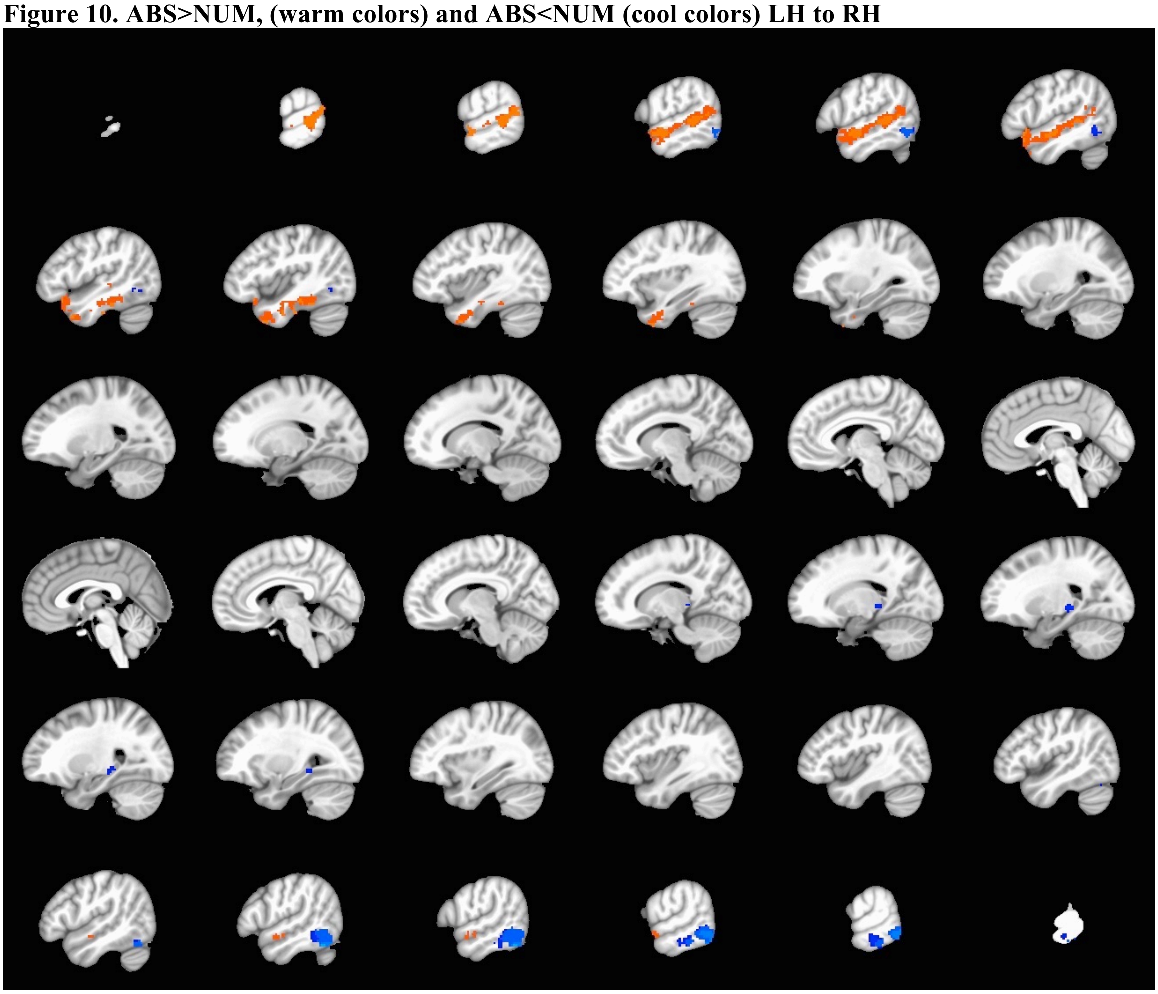


Table 2. ABS vs. NUM

Contrast	Voxels	CM x	CM y	CM z	Px	Py	Pz	Structure
abs>num	884	-57	-24	-2	-53	20	-5	LH STS, STG, MTG, TP
	305	-41	-10	-30	-43	-23	-32	LH MedTP, ITG, FG
	49	57	-2	-11	63	2	-12	RH STG, TP
num>abs	464	60	-49	-13	60	-53	-22	RH ITG, MTG
	85	-53	-61	-9	-60	-63	-15	LH ITG
	53	24	-32	-4	30	-38	-7	RH PHG

Discussion

One of the most notable aspects of the results for the ABS>NUM contrast is how anterior the activations are. For instance, we show a 305 voxel cluster that runs along FG, ITG, and medial temporal gyrus, and reaches y=14.5mm (MNI, LPI) in the medial temporal pole; and y=24.5mm in the pole's superior aspect — the absolute anterior limit of temporal lobe anatomy. This is especially interesting because a task that has proved robust in eliciting polar activation for other labs involves processing the most specific-possible semantic constructs: famous faces, landmarks, and other unique entities (Drane et al. 2008, 2013; responses to similar stimuli reviewed in Ross & Olson 2012). It is noteworthy, then, to achieve such thorough activation in this same region using a task with the least-specific stimuli possible. Moreover, the cluster's posterior limit extends to fusiform gyrus, a region consistently associated with processing highly imageable (aka, concrete) stimuli by virtue of its position in the ventral visual processing stream (Chao et al. 1999; Kravitz et al. 2013).

Also worthy of comment is the 49 voxel cluster in the RH, from middleTG to STG just caudal to RH temporal pole at y=4.5mm. Though our results are heavily left-lateralized, as predicted, this RH activation is noteworthy for the same reason given for the contra-lateral ROI described above: in spite of theories that suggest it plays a part in the 'concrete advantage' that accrues to concrete semantics (Paivio 1991) or alternately anchoring a bilateral, amodal hub (Patterson et al. 2007), we show RH TP active to our most general abstract contrast. This is an ROI also featured in the results from Sabsevitz and colleagues (2005) using a similar triads task, and from Skipper and Olson (2014), but absent in the results of Noppeney & Price (2004) who also used the triads task; however, we later outline a caveat regarding differences between their results and ours.

Moving more caudally in the RH, the activation in pMTG for the "reversed-direction" NUM>ABS contrast is one instance of a result that we will subsequently see is common to all of our semantic classes —that is, similar findings were obtained in the NOV>NUM, ABS>NUM, and CONC>NUM contrasts. This region has been implicated in the processing of numerosity by Wei and colleagues (2014), also using a triads task; these researchers found similar activation in this RH region in response to not only number words (as in various of our contrasts) but also to Arabic digits, and to differently-sized clouds of dots in contrast to animal names. The appearance of this activation cluster in response to such diverse number-cognition stimuli and across studies is encouraging; as is the fact that the subjects in this case were Chinese, and the orthography also Chinese, thus obviating criticisms about Western bias in many psychological studies (Henrich et al. 2010).

Returning to the LH, the extent of the 884 voxel 'long-axis' cluster along the LH STG/STS/MTG is far broader than one would predict based on meta-analytic results involving abstract semantics as described in the overview. We will refer to this cluster as the "Royal Road" (RR), since it will come up repeatedly in the course of our analyses, and because its extension and contiguity suggest a road. The long caudal-rostral sweep of the RR is traditionally the signature of whole-sentence processing and is ubiquitous in that literature (Friederici 2012; Mar 2011). Its appearance in the results for the current contrast and task, which uses a triad of words lacking sentential context, suggests that it is not sentence processing per se that so forcefully calls forth a response along the major temporal axis, but rather some other factor which sentence processing must express to an especially high degree.

The activity gap between the RR and the meta-analytic results becomes less egregious when we compare it with findings from several studies, mentioned in the introduction, that use stronger semantic tasks. In particular, Sabsevitz and colleagues (2005) and Skipper & Olson (2014) show extensive activation along STS that is commensurate with our own. At this point it seems plausible to hypothesize that a more demanding semantic task, like a triads task (Sabsevitz et al. 2005), or a single-word task designed to engage "deep" processing of semantic features (Skipper & Olson 2014) may activate the temporal lobe in general, and the RR in particular, more than has been usual in the literature; and that the failure of work summarized in meta-analyses to produce anything comparable is due to the weaknesses of the tasks that have, to this point, been more frequently used in semantic investigations. At first blush this might, though, not seem to be a very satisfying hypothesis, since another experiment using a triads task that we have already discussed (Noppeney & Price, 2004) does not show a comparable activation in the same region; however, as we will demonstrate in the section on concrete semantics, this difference seems to be explainable by the peculiarities of the concrete stimuli used by those authors (Binder et al. 2009).

One difference between our results, and the results from the aforementioned studies using very similar tasks, involves the region of medial activation we demonstrate around FG/ITG. Since the present ABS>NUM contrast has a non-semantic control (at least to the extent that making relative numerical magnitude judgments about sets of words denoting numbers is non-semantic, an assumption with some precedent, e.g. Binney et al. 2010; Pobric et al. 2007; Wei et al. 2014), and the ABS>CONC contrasts in the previous studies (Noppeney & Price 2004; Sabsevitz et al. 2005) do not, it is possible that these medial activations are common to both ABS and CONC semantics, and are either subtracted out, or inverted, when ABS is compared with CONC. We will have a better sense of this in later sections when concrete semantics are examined and when the two are compared directly. However, it's useful to know that the region _is_ demonstrably recruited in response to a task using abstract stimuli. Yet, not just any task will do: even an experiment featuring a "deep processing" task using single word stimuli that produced relatively broad activation in the anterior half of the RR (Skipper & Olson

2014), and which also reported results using a non-semantic control (non-words), did not show results as medial as ours. One might explain the inconsistency by proposing that even a block-design task where subjects were instructed to think deeply about the meanings of the words does not require the same degree of “semantic horsepower” as our triads task.

Emotional contribution to abstract semantics

Overview

Many imaging experiments that investigate semantics are confounded by stimulus features that are not of experimental interest. For instance, abstract words typically contain more emotional content than do concrete words (Kousta et al. 2011). As a result, if emotionality is not controlled then it's possible that what appeared to be a difference between abstract and concrete could really be due to differences in the emotional content between the two classes; and it's possible that the neural response to abstract semantics in general could be partially driven by the emotional content of the semantic stimuli used to investigate it. As described in the introduction, this confound has led to widely disparate interpretations of the results of existing semantic experiments, and theories as to the neurological processes that gave rise to them.

We will attempt to "smoke out" the emotional contribution to the semantic response in three ways.

First, we will examine the results of a separate emotional localizer that contrasts a stream of negatively-valenced words vs. a stream of neutral words. This will tell us about the system's basic emotional response to a task involving single words with no overall semantic meaning (i.e., the sequence of words is not a sentence, and the words presented do not build to an aggregate meaning). If the emotional response revealed by this contrast is similar to the semantic response from the ABS>NUM contrast, we'll know that we must work carefully to disentangle the emotional contribution from the non-emotional semantic contribution, if such a disentangling is even possible.

Second, we will examine the emotional nuisance regressors associated with the abstract triads in the ABS>NUM condition. These nuisance regressors are included in all our analyses of the abstract triads stimuli, as described in the methods section, and serve to `soak up' the voxels' response to variations in emotionality. Though this emotional contribution to abstract semantics will have been absorbed into the nuisance regressors and thus absent from the various ABS contrasts, we can nonetheless examine the BOLD response to these regressors to see how variations in our stimuli's average emotional valence and arousal modulate activation to the ABS condition.

Finally, we will examine a contrast between the high-arousal ABS words vs. the low-arousal ABS words. This contrast will show us if some emotional response `escaped' the nuisance regressors, and mixed in with the general semantic results. Similar to the emotional localizer discussed above, the results of this contrast will tell us how tangled our semantic results are with triads' emotional content. If they are very tangled — if they activate the same regions — then interpretation becomes more difficult.

The purpose of these tasks and contrasts is to separate emotional from general semantic content. Such a separation is necessary because emotionality (among other factors) is frequently confounded with `general' semantic processing in semantic-cognition experiments. A consequence of this confounding means that it's difficult to know what to predict based on existing results from the literature. For instance, the results of a recent meta-analysis on this topic (Binder & Desai 2011) show relative activation increases in response to emotional semantic stimuli that are dispersed across both the left and right TL, medially and laterally. The heaviest concentration of activation is in ATL, but activations also appear in posterior regions that border the occipital and parietal lobes. Of course, many of these `emotional' results are also "polluted" with general semantic content, which means that the similarity of these emotional meta-analytic results to our own semantic results (especially in LH) could be due to the general semantic content in these putatively emotional experiments. Stated differently, the confounding cuts both ways.

That said, there is an intriguing case to be made for bilateral TP as a region of particular significance in emotional processing. As has been discussed in the introduction, ATL in general and TP in particular are inconsistently activated in semantics tasks. However, the TP is reliably activated bilaterally in response to social stimuli presented in words or pictures (Olson et al. 2007), and since social words deal with people and social situations, they contain more emotional content. When considered in light of TP's proximity to the uncinate fasciculus (Harvey et al. 2013; von der Heide et al. 2013), this suggests that activation in the ROI could arise from the marriage of semantic content, subserved by temporal lobe structures, to emotional and motive valuation provided by frontal structures. While the semantic interpretation seems more straightforward, emotional activation in LH TP would be theoretically justified, so if there is going to be an emotional semantic contribution it seems reasonable to expect to find it here.

Methods

Method 1: Emotion localizer

Stimuli

The emotion localizer presented blocks of words. Each block contained one of 3 types of word stimuli: positive words, negative words, and neutral words. The chief difference between these classes of words is in the valence of the emotional content associated with the words, measured in terms of valence and arousal, summarized in the table below. (Description of and origin of the other features listed in the table is explained in the overall triads methods section.)

Table 3. Feature statistics for emotion localizer stimuli. KEY: Val=valence; aro=arousal; freq=written frequency; let=number of letters; syl=syllables; cnc=concreteness; img=imageability.

Stimulus type	Avg val	Max val	Min val	Avg aro	Max aro	Min aro	Avg freq	Avg let	Avg syl	Avg cnc	Avg img
Negative	2.06	2.5	1.39	5.85	7.97	3.83	26.84	6.86	2.13	423	481
Neutral	5.16	5.75	4.32	4.06	6.61	2.92	44.46	6.03	1.88	547	543
Positive	7.92	8.72	7.5	5.78	8.02	2.95	49.17	6.80	2.10	419	507

Task

Subjects performed one run of the emotion localizer in each session, in which they were presented with a block of 15 words, one at a time. Each word was on the screen for 500 ms, followed by a fixation cross for 300 ms. Subjects were instructed to press button 1 whenever a word repeated. Words repeated three times during the course of each block. Blocks were preceded by a 12 second fixation cross. There were 3 block types: POS (positive words), NEG (negative words), and NEUT (neutral words). Block type transitions were balanced so that every block type transitioned to every other block type an approximately equal number of times. There were 8 blocks of each type. The order of blocks was the same for all subjects.

Behavioral results

Figure 12 presents accuracy on the repetition-detection task. Even when subjects' responses were interpreted as generously as possible (to be described momentarily) their performance on the emotion localizer was worse than on any other task or condition.

Figure 11. Per-subject accuracy across all tasks.

Interpreted strictly, an accurate response during the emotion localizer task means that when a word presented to the subject was a repeat of the previously presented word, that the subject pushed the button before the successive word appeared on the screen; on the other hand, failing to push the button before the onset of the successive word would count as an error.

However, in practice it was difficult for many subjects to meet this strict performance requirement, and so to get a more reasonable picture of subject performance we created an alternate, more generous interpretation of what could count as a correct response. In this more lenient scoring approach, a button press that ‘spilled into’ the next word’s presentation was credited as a hit, under the assumption that subjects intended to push the button during the repeated word but could not manage to do so in time.

One danger with using this generous formulation is that a subject could potentially achieve an inflated score by button mashing – simply pressing the button constantly, regardless of whether the word on the screen was a repeat, would result in a perfect score. To verify that the subjects were not employing such a strategy we examined both the number of ‘late hits’ (button presses that occurred during the presentation of the word immediately *after* the duplicate word) and false positives (button presses that occurred during non-duplicate words, excepting the false positives that were credited as late hits). The data across all subjects are presented in Figure 13.

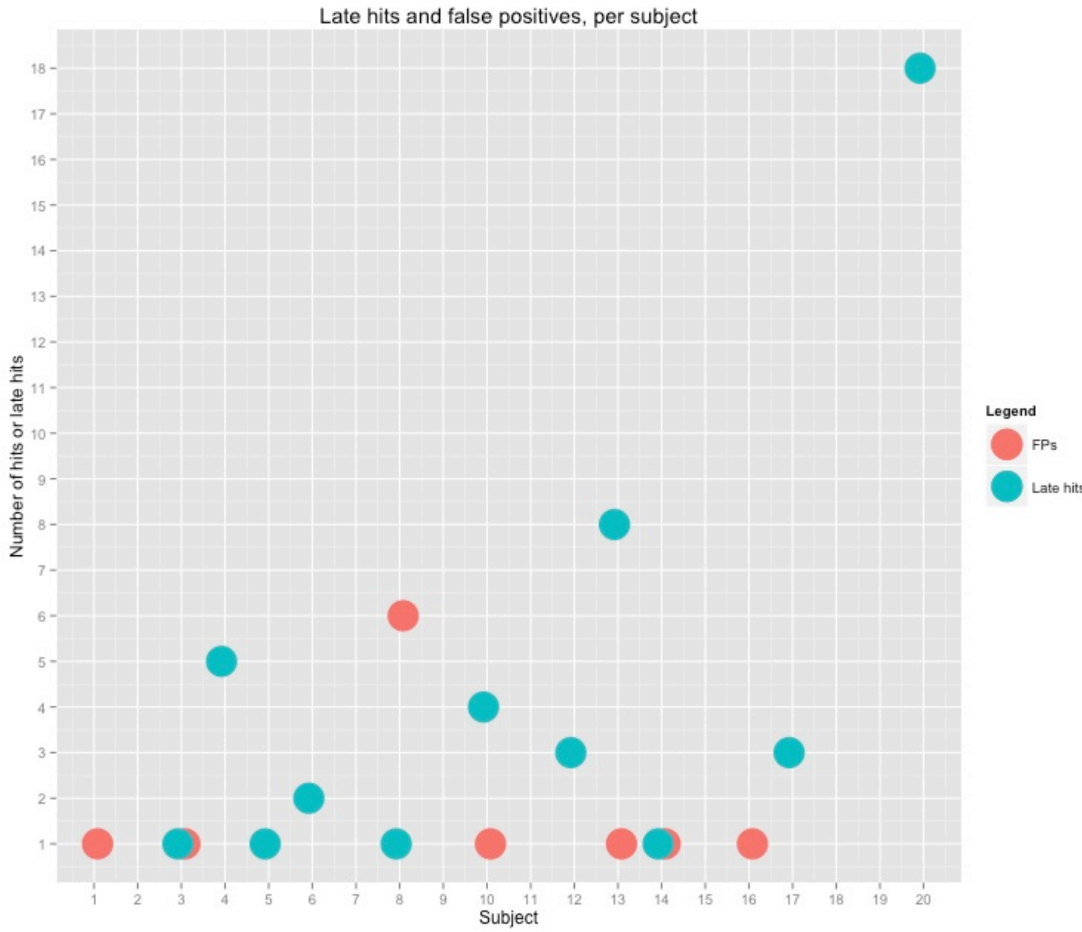


Figure 12. False positive responses, with responses that would otherwise be considered false positives re-classified as late hits.

It is obvious from this figure that no subject was using a button-mashing strategy; that false positives were quite rare; and that subjects who performed poorly on the task seemed to be making a good-faith effort. For instance, subject 20, who showed the lowest overall performance on this task, made 18 late hits, suggesting that he attempted to do the task but could not meet its performance requirements. This is in accord with subjects' performance across the preceding tasks, which was consistently high. Based on these results, it seems clear that even though overall accuracy was lower for the emotion localizer task, even poorly-performing subjects were likely attending to and engaged with it, and the imaging data that resulted from it can therefore be trusted as an accurate manifestation of brain activity under specified task conditions.

Image analysis

Pre-processing occurred as described in the general methods. The normalized emotion localizer data were then used as input to a general linear model. In a block design, three regressors of interest corresponding to events of each block type (POS, NEG, NEUT) were convolved with a block HRF with a twelve second window. Nuisance parameters were included and censorship was implemented as in the triads task. Solving the GLM resulted in 2 statistical parameter maps per subject (one for each session). These session maps were then averaged together for group analysis to produce the final aggregated maps.

For our random-effects group analyses, we performed one-sample t-tests (vs. 0) on the difference between parameter estimates for the NEG block vs. the NEUT block[1]. We performed group-level tests at two significance thresholds. The first thresholded results at standard per-voxel significance of $p < 0.001$, and cluster-wise significance of alpha < 0.01. Since the results of this analysis were so sparse, we performed an additional analysis at a relaxed threshold of per-voxel $p<0.01$ and cluster-extent thresholded at 20 voxels (producing minimum admissible alpha > 0.1).

Method 2: Valence and arousal regressors

As described in the general methods, ratings for the emotional valence and arousal of each triad were included as nuisance variables in the general linear model by which voxel activity in response to the experimental conditions was computed. To see the contribution of this latent emotional content (as measured by valence and arousal ratings) to the activation produced by abstract triads we next examine these `nuisance' regressors themselves.

Though normally we examine parameters in a subtractive context in order to eliminate commonalities (e.g., testing the significance vs. zero of the value of the ABS

[1] We omit the positive (POS) block from our analysis as our results indicate that it does not provide any additional distinction in comparison with the other emotional conditions: POS contrasted with NEUT shows a comparable, but weaker, extent of activation as NEG contrasted with NEUT, whereas POS vs. NEG reveals no significant activations at all.

regressor minus the value of the NUM regressor) in this case we will test the significance of the VALENCE and AROUSAL regressors directly, since the other elements of semantic processing have been shunted into the other parameters. The result of this examination will reveal the per-voxel variance owing to emotional processing being absorbed into these regressors, a contribution that is not included in the general triads analysis. This examination of the valence and arousal nuisance regressors produced no activations at standard statistical thresholds, so in both cases we report results at the same liberal statistical thresholds as used for the emotion localizer.

Method 3: High vs. low arousal and emotion/abstract interaction

However, it's possible that these valence and arousal nuisance parameters could be unable to capture the emotional content latent to abstract triads owing to insufficient leverage due to per-condition rating similarity. To test for this degenerate circumstance, we combined both abstract conditions (HSS, LSS) together and then split the combined set into two groups based on the median arousal rating. (We then did the same thing for both concrete conditions (CNM, COM) to support the interaction test, as described below.) We then contrasted the ABSTRACT_EMO_HIGH group vs. the ABSTRACT_EMO_LOW group. We first analyzed the results of this contrast at standard per-voxel significance of $p < 0.001$, and cluster-wise significance of alpha < 0.01. Since the results of this analysis were so sparse, we performed an additional analysis at a relaxed threshold of per-voxel $p < 0.01$ and cluster-extent thresholded at 20 voxels (alpha > 0.1).

We also performed an interaction test to see if the concreteness of the triads (as embodied by the difference in our abstract and concrete stimuli) and the emotional content of the triads (as embodied by the split of the abstract and concrete triads into EMO_LOW and EMO_HIGH groups) combined to produce a non-linear influence on brain activation. One can compute interactions in a variety of ways; the simplest for our purposes was to use a t-test with a `double subtraction' methodology, and test the following parameter formula vs. 0:

abs_emo_high - abs_emo_low - conc_emo_high +conc_emo_low

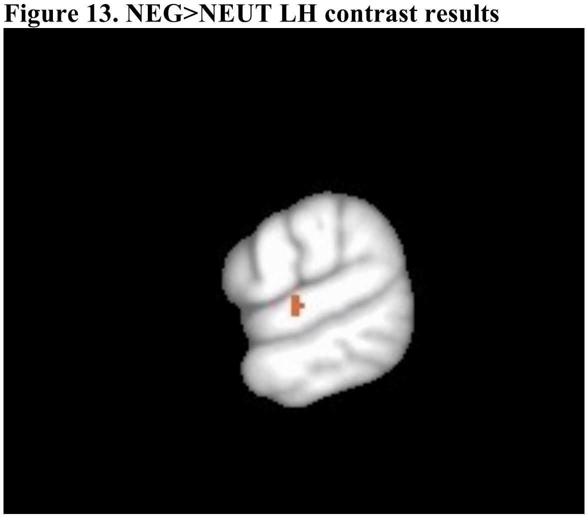
If the above quantity is significantly different from zero, it means that abstractness and emotion (arousal, in this case) are interacting in a non-linear fashion.

Results

Emotion localizer

NEG>NEUT at standard statistical threshold produced 33 voxels in LH STG.

Figure 13. NEG>NEUT LH contrast results



NEG>NEUT at relaxed threshold ($p<.01$, 20 voxel cluster threshold) produced a number of activations, the most extensive of which occurred in LH.

Figure 14. NEG>NEUT LH contrast results at p<.01, showing only clusters > 20 voxels

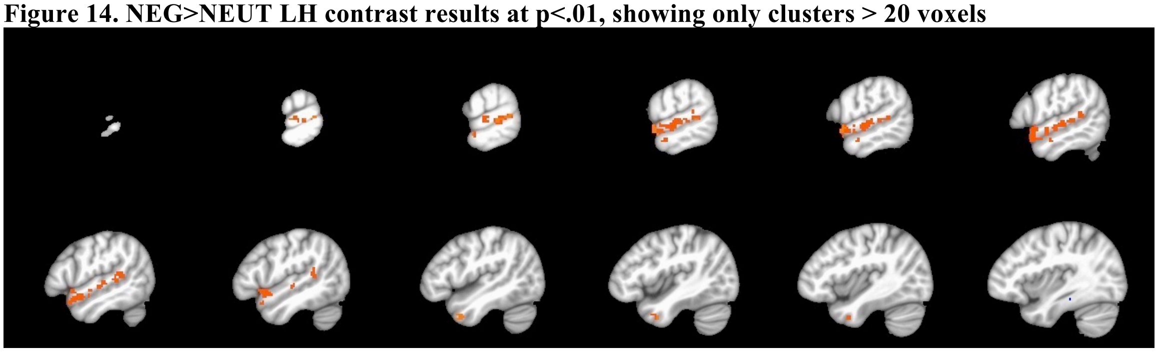


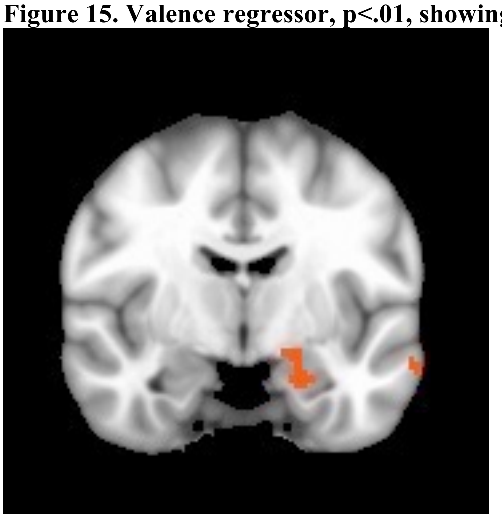
Table 4. NEG vs. NEUT

Contrast	Voxels	CM x	CM y	CM z	P x	P y	P z	Structure
neg>neut	377	-58	-16	-1.4	-60	7	-5	LH TP, STS,STG,MTG
	29	59	-22	1	60	-23	1	RH STG
	28	53	-33	7	55	-33	3	RH STG
	26	-44	7	-38	-45	7	-40	LH ITG, MedTP
	22	-61	-7	-16	-65	-6	-12	LH MTG
neut>neg	69	-29	-34	-13	-33	-33	-15	LH FG

Valence and arousal nuisance regressors

The valence regressor at the relaxed threshold (p<.01, 20 voxel cluster threshold) produced two clusters in LH. The arousal regressor at the relaxed threshold (p < 0.01, 20 voxel cluster threshold) produced no surviving results.

Figure 15. Valence regressor, p<.01, showing only clusters > 20 voxels



Abstract words high- vs. low-arousal

The abstract words were split into high arousal (AHO) and low-arousal (ALO) groups and contrasted against each other. The results of the AHO>ALO contrast produced no significant clusters even at the extremely lax p < 0.01, 20-voxel cluster threshold.

Abstract/emotion interaction

The abstract/emotion interaction contrast produced one cluster of 47 voxels in LH STG at the standard statistical threshold.

Figure 16. Abstract/emotion interaction with image shown in radiological convention

Table 5. Abstract/emotion interaction clusters

Contrast	Voxels	CM x	CM y	CM z	P x	P y	P z	Structure
a/e inter	47	-63	-48	12	-65	-58	8	LH STG

Discussion

The most surprising finding is that the NEG>NEUT emotion localizer produces negligible results at standard thresholds. At more relaxed thresholds the findings along LH STG to TP appear highly similar to Royal Road results in our ABS>NUM contrast. One could argue that these results are due to either the emotionality latent in the semantic information, or simply the semantic information itself, regardless of emotionality. Fortunately, we have other evidence that will allow us to fix some of these degrees of freedom.

First, the nuisance regressors capture the contribution of emotional valence / arousal from within our ABS>NUM contrast; however, as we have seen the voxels modulated by these parameters are minimal, and do not include the regions in question.

Second, we explicitly split the ABS triads into high- and low-arousal conditions. A contrast between these conditions reveals no activation even at very liberal statistical thresholds. The results of the emotionality/abstract-ness interaction test do, however, identify a region in posterior STG, which is on the RR. This suggests that while emotional content does not directly drive activation in TL, it may do so indirectly in pSTG, perhaps by adding extra emotional salience to abstract semantic content.

Interpreted in light of our ABS>NUM results, the findings from these emotional contrasts suggest that emotional information has little to do with the massive extent of activation in TL revealed by our ABS>NUM contrast. This is somewhat surprising. While ATL theories are highly entropic, the anatomical argument for ATL's involvement with emotional content is strong. Moreover, both the results from `emotional' semantic contrasts as reported in Binder and Desai (2011), as well as the copious activations of the region using social stimuli, which are also often confounded by emotional content, suggested _some_ role in processing emotional information in ATL/TP; and yet our direct investigations of this question, using multiple tasks and contrasts, do not support that interpretation.

With regard to the rest of TL, Binder and Desai's (2011) meta-analysis shows a number of emotion-related activations in posterior and lateral LH. Our ABS>NUM contrast also produces extensive activation in proximate regions, even after controlling for valence and arousal by including parameters for those variables in the regression model. A pertinent concern is whether emotional content could be `leaking out' of our nuisance regressors and into these voxels (a possibility that could occur under certain pathological distributions of valence and arousal in our triads stimuli) or whether they are simply responding to general semantic information. The present findings suggest the latter.

Though we did not find evidence for an emotional contribution to activation in ATL in particular, nor even most of TL in general, it's worth asking whether these tasks and stimuli are adequate to address such a question.

With regard to the NEG>NEUT emotion localizer, the lack of results might be due to the nature of the task, in which subjects view a series of words flashing in the center of the screen, one at a time, and push a button when a word repeats. If the emotional content of the word stimuli is associated with the semantic features of the stimulus word (vs. lexical features that might be accessed automatically in the course of reading) then the task, which requires no semantic elaboration to perform, may only weakly engage the emotional content of the stimuli, since it has been established that, at least in some circumstances, un-needed semantic aspects of a word are not accessed automatically during tasks in which surface statistics suffice (Lebois et al. 2014; Solomon & Barsalou 2004). The danger of this possibility is why we chose the triads task for our semantic condition, vs. a task like lexical decision, which has been observed to generate weak results when compared to other semantic tasks (e.g., Kiehl et al. 1999). It is therefore possible that the emotional content in our stimuli was less salient in the course of reading the words for the purposes of repetition detection, than it would seem to be when the words are read in isolation.

This is a plausible explanation; however, it should be noted that the same triads task that produced extensive activation in the ABS>NUM contrast also revealed negligible emotional contribution to ATL when the emotional components of the triads were tested directly, either by splitting the stimuli into low- and high-emotional groups, or by examining the valence and arousal regressors into which the emotional response was funneled in the GLM. Still, while we have some assurance that the triads task is good at eliciting thorough semantic processing (judging by the extent of activation from the ABS>NUM contrast) it remains true that attending to, or processing, the emotional features of the stimuli was not required to perform the task. In other words, for the same reasons the triads task produces a more robust semantic response than does a lexical decision task, it is possible that if emotional content is not necessary to perform the task then it will produce a weak result (or no result) regardless of the emotional strength of the stimuli. In addition, the task structure of the emotional localizer—involving blocks of 15 items all with negative emotional valence or neutral valence—might be argued to promote the ready extraction of valence (cf. studies of the contribution of semantic similarity to episodic memory, that use blocked vs. randomly intermixed presentations of items to promote semantic gist extraction, e.g., Mather et al. 1997; Toglia 1999).

Taken in aggregate, and with the caveats mentioned above, there is little evidence for, and much evidence against, the interpretation that TL cares about the emotional content of stimuli during semantic processing.

Social contribution to abstract semantics

Overview

Just as some researchers suggest that ATL/TP is primarily involved in representing emotional information, some suggest it is principally involved in processing social information. Once again, this would explain both the inconsistent results obtained in many semantic tasks (since the social component of the stimuli is often un-modeled) as well as the wide range of seemingly disparate tasks that engage the region (since diverse tasks and stimuli can include hidden social elements).

To test the ATL's sensitivity to social stimuli we wanted to find, as closely as possible, the neural signature of social processing unadulterated by any semantic representational issues or emotional content. We approached this by contrasting abstract words of high (HSS) and low (LSS) social strength, with the emotional aspects of valence and arousal eliminated from the model with nuisance regressors, as described in an earlier section.

We predict that, consistent with the results reported above, this contrast will show activated regions in temporal pole. The fact that in our task the social information is mediated through word stimuli suggests the activation might be restricted to LH (the language-dominant region) and the superior gyrus, since the STG has been shown to preferentially activate in response to words, both written and spoken, and possibly because of TP's connection through that convolution, via the uncinate fasciculus, to orbito-frontal regions associated with emotional processing.

In addition to the standard univariate analysis, we will also examine the HSS vs. LSS comparison using an informational searchlight analysis (Kriegeskorte et al. 2006). The predictions are the same for this analytical method; as described in the introductory methods section, the searchlight analysis is included so that we might have increased power to detect patterns that occur across a group of voxels, and that are not detectable using traditional univariate techniques.

Methods

Stimuli

Based on available norm data, as described in the overall triads methods section, the HSS and LSS stimuli moderately differed in mean concreteness and arousal. They did not differ on other tracked features. The result of feature comparisons between the conditions are summarized in the following table.

Table 6. Feature differences between HSS and LSS. KEY: conc=concreteness; imag=imageability; val=valence; aro=arousal; fam=familiarity; avg_let=average letters; avg_syl=average syllables; kucera=Kucera written frequency

	conc	imag	val	aro	fam	avg let	avg syl	kucera
HSS	329	415	5.7	5.3	533	5.6	1.9	77
LSS	360	411	5.5	5	541	5.8	1.9	90
p-val	p < .05			p < .05				

Image analysis

We tested the univariate results of the HSS-LSS contrast, as described in the triad methods overview. We also used an information searchlight to test the pattern classification ability of the HSS vs. LSS conditions, as described in the searchlight methods overview.

Results

Univariate results

Using the standard statistical thresholds ($p < .001$ and $\alpha < 0.01$) the HSS>LSS contrast produces no active clusters. Relaxing the thresholds (to $p < 0.01$, then including only clusters of at least 15 voxels) produces two active clusters for HSS>LSS, both with alpha > 0.1. The first is in LH TP; the second is in LH HPC.

Figure 17. HSS>LSS contrast results in LH, at p<.01, thresholded at clusters of at least 15 voxels

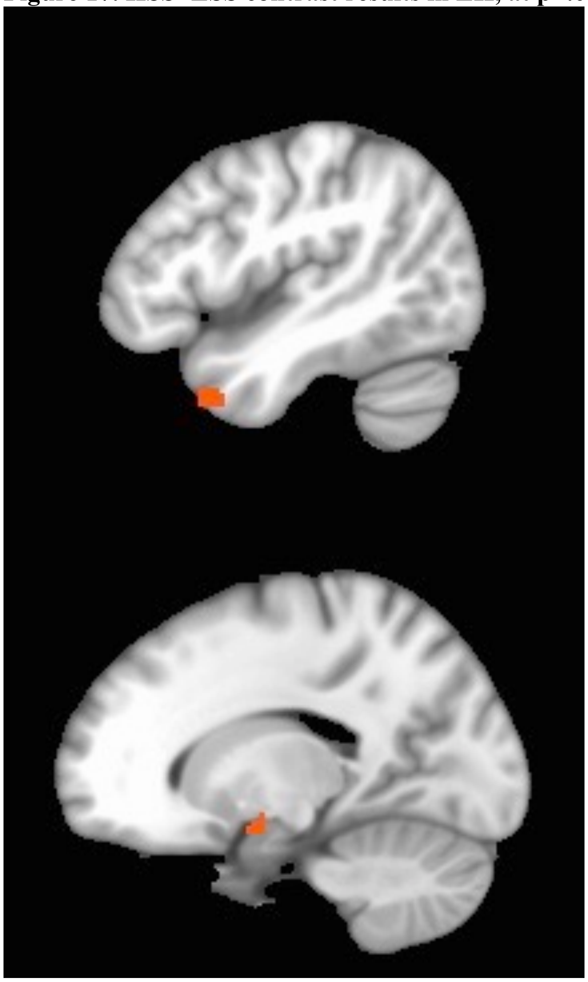


Table 7. HSS>LSS clusters

Contrast	Voxels	CM x	CM y	CM z	Peak x	Peak y	Peak z	Structure
hss>lss	17	-45	14	-37	-45	15	-37	LH MedTP
	16	-17	-4	-14	-15	-3	-15	LH HPC

Searchlight results

Information searchlights with radii of 3 and 5 voxels failed to produce any cluster of more than five voxels that reached above-chance performance in classifying HSS vs. LSS, even at the relaxed statistical threshold of $p < 0.01$.

Discussion

The HSS>LSS contrast produced no significant results that survive standard significance testing in our univariate analysis. It is intriguing, however, that the left-lateralized polar activation visible at the relaxed $p < 0.01$ level is consistent with some accounts of the location of activity under the social processing hypothesis (Ross & Olson 2010, social-semantic vs. animal task; Skipper et al. 2011) but not others (Zahn et al. 2009b, where results are right-lateralized.) These results are therefore consistent with the pattern of inconsistent results.

However, it's also true that the social processing hypothesis leads us to expect a much more robust effect than our sub-threshold results suggest, especially in light of the activations we can observe in this same region for other of the triads contrasts described elsewhere in this paper. If we're confident that our triads task is sufficiently semantic (Visser et al. 2010) as to elicit strong responses in this difficult-to-image region — and results from other contrasts show that we can, indeed, achieve statistical significance in many ATL regions — and if other researchers have consistently found results in this same ROI from experiments using social stimuli, then what might explain our weak (or almost non-existent) results for this social contrast?

One possibility is that the social information latent in our triad stimuli is encoded in patterns undetectable by traditional univariate fMRI analysis — perhaps the mean activation of the voxels is the same, but the pattern within a group of voxels is distinct between the classes (Norman et al. 2006). In other words, it's possible to have different patterns encoded in a region that have no discernible mean activation differences.
To test this idea, we used an informational searchlight (Kriegeskorte et al. 2006) that tested classifier performance on the HSS and LSS conditions. Prior research suggests that a variety of regions in TL should be sensitive to social information, but particularly LH temporal pole. However, information searchlights also failed to find neighborhoods containing pattern information that could distinguish HSS and LSS stimuli.

This means that neither of our analytical methods were able to discover a distinction within the bounds of our temporal ROI between high- and low-social-strength stimuli that met standard statistical significance testing thresholds, despite an abundance of evidence in the literature that anterior temporal regions are exquisitely sensitive to social content.

One possible explanation for this lack of results (at standard statistical thresholds) is that the social distinction instantiated in our high- and low social strength stimuli is just not very salient. This is not as paradoxical as it might appear at first. The words used in our social conditions were initially selected from a candidate list of abstract stimuli obtained elsewhere, and only thereafter assessed in terms of their social significance. A cursory examination of the stimuli will reveal that, for most people, the social aspect of these words will not jump off the page. Requiring raters to give social ratings for inherently non-social words may be akin to asking people to rate unliked foods on a scale of 1-7: the resulting food ratings may well be spread throughout the range of possible values, as one develops a more sophisticated 'palette' in rating the relative merits of the sample, but a more salient way of considering the stimuli would be as a single group of un-liked foods. Put in statistical terms, the social-ness of our social words may have lacked sufficient leverage to create meaningful distinctions between high and low, with the result that the variable of interest was erased from the contrast (Visser et al. 2010.)

A further, not unrelated point concerns the possible contribution of individual differences in the interpretation of the degree of “social relatedness” of the triads: The triads were classified into high vs. low social relatedness by a different group of participants, and if there are substantial individual differences in how words are evaluated on the “social relatedness” dimension, our normative classifications of the stimuli might not closely correspond with the classifications that our scanned participants would have provided (had they been asked to make such explicit judgments).

Our stimuli are also atypical when considered against the larger body of work on social cognition and its manifestation in anterior temporal lobe (see Wong & Gallate 2012 for an overview). The vast majority of the experiments from this literature use social stimuli that are richer and more multi-modal than are the triads used in our experiment. Common alternatives use stimuli evocative of theory of mind (den Ouden et al. 2005), or pictures of faces (Tsukiura et al. 2011), or sentences about people interacting

(Binder et al. 2011b) or full sentences that pose moral quandaries (Heekeren et al. 2005) to exercise the semantic system and coax activation from the ATL. These stimuli are richer not only in their social content, but in a variety of other semantic aspects, some of which covary with social content. For instance, social information is often about particular people doing things, which is confounded with another prominent theory of ATL function which describes the region as mediating access to unique entities like faces (Drane et al. 2013, Drane et al. 2008; Tranel 2006) or to faces and landmarks when they are labeled with proper names (Ross & Olson 2012). So it's possible that our social stimuli were simply deficient in the kind of `social bandwidth' that elicits ATL involvement.

Nonetheless, it's worth noting that in the few studies where these confounds are addressed directly, the ATL's preference for social information remains. For instance, Simmons and colleagues (2010) created a unique entity (UE) experiment in which they varied the amount of entity-specific information associated with people, hammers, and landmarks. ATL activity was significantly higher when processing the specific-level person information, but not when processing the other classes even though they were also annotated with specific-level information. Tsukiura and colleagues (2008) used a similar task, in which subjects who were taught specific, differentiating information to associate with unfamiliar faces, also showed activation in temporal pole when retrieving the differentiating information associated with the names of those faces. In an experiment that also tested the effects of imbuing various kinds of specific information into social (faces) and non-social (geographical landmark) stimuli, Ross & Olson (2012) found that, while non-social information (landmarks) showed a specific-level effect in ATL, the response to specific landmarks was smaller than to both specific and non-specific faces. Taking these results together one might conclude that ATL is preferentially sensitive to social information in general, but particularly sensitive to social information associated with unique conspecifics — people, in the case of human subjects. This would account for the lack of activation we find in the present social strength contrast, since the social content of our stimuli does not explicitly map to any particular person. Based on this idea we might hypothesize that had our social stimuli been more pointedly directed toward a particular target (a face; the name of a person) we might have replicated the ATL findings that other labs report.

That said, the results from one foundational exploration of social cognition in ATL (Zahn et al. 2007) stand in special contrast to our own. In this early work, Zahn and colleagues presented subjects with dyads composed of either social words (HONOR/BRAVE) or animal function words (NUTRITIOUS/USEFUL). The subjects' task was to indicate whether the words in the dyad were related in meaning. The results of contrasting the social words vs. the animal function words produced a number of activations, notably (for our purposes) bilaterally in superior ATL and in RH middle temporal gyrus, though activations posterior from the pole compared to our trending results. This shows that it's possible to find activations as a result of a social manipulation using two words and a task that requires moderate elaboration of the words' features to perform correctly — stated differently, if they did it with their stimuli, there's reason to believe we could do it with ours. Still, returning to the point from the previous paragraph, even with more subjects, fewer experimental contrasts, and stimuli tailor-made to exercise social semantics, the positive results from Zahn and colleagues for SOCIAL>NON-SOCIAL are considerably less extensive than results from social tasks that use, for instance, Heider and Simmel movies (Ross & Olson 2010), which suggests that the nature of the social stimuli is an important factor in the strength of the social response. Social tasks that involve observing body movement, mouth and hand movements, lip reading, and eye gaze produce peak activations along the full extent of STS, sometimes poking into STG, sometimes into MTG (see review in Allison et al. 2000). This is precisely the Royal Road region that differs between our results for abstract triads (as reported in an earlier section) and the majority of results in the literature, which makes the lack of activation to the present social contrast so puzzling.

It seems clear from these results, or lack of them, that while it's possible that social information plays an important role in semantic processing, the social content of our triads is not driving the extensive activations in our abstract contrast; and while various flavors of social processing are clearly important throughout temporal lobe, additional work is needed to operationalize the particular social aspects of stimuli that drive activation, and that can predict where in temporal lobe that activation will occur. Non-sentential word stimuli with a patina of social association like those used in the experiments of Zahn and colleagues (2007; 2009a, 2009b) can produce activations in certain circumstances, but these stimuli are not representative of the social information hypothesis, and do not appear to strongly characterize TL function, as our lack of results using similar stimuli demonstrates. Where the social information hypothesis is concerned there must be more to the picture.

Concrete triads

Overview

Continuing our tour through the semantic system, we would like to see how concrete concepts are represented. We have two types of concrete stimuli to help us investigate this question, concrete natural multi (CNM) and concrete one-modality (COM) triads. CNM triads contain words describing creatures (animals, insects, birds), fruits, and vegetables; COM triads contain words describing shapes, colors, and sounds.

Though the words in both conditions are concrete (they refer to things in the world that are detectable through our senses), they differ in several respects; most broadly, they differ in regard to the number of SM components they include. For instance, a SCORPION has a certain shape and color; but it also moves a certain way, is found in the desert, can kill you if it stings you, etc. This is a much richer bundle of content than is required to process the word BUZZING which is defined overwhelmingly through its auditory characteristics.

Meta-analytic results for concrete semantic tasks show activity in regions that have been shown to respond to a variety of visual features. Why should this be?

There's a great deal of overlap and interdependency between perceptual and conceptual processing (Kravitz et al. 2013; Meteyard et al. 2012). For instance, although ITC was initially considered a purely visual area (Logethetis & Sheinberg 1996), later work has shown it to be involved in conceptual representation. In contrast to early visual areas like V1, which are organized around their fine-grained response to low-level image characteristics (Hubel & Wiesel, 1968; Parker & Hawken 1988), sub-regions in ITC make broader categorical distinctions, so that representations of faces, animals, and tools are grouped together despite within-category perceptual dis-similarities (Martin 2007). This is true across a variety of categories, and has been observed in both humans and monkeys (Kiani et al. 2007; Kriegeskorte et al. 2008). Even blind subjects show coherent categorical regions in IT (Striem-Amit et al. 2012), and the region has also been found to activate to semantic content presented in non-visual modalities, including auditory sentence comprehension (Rodd et al. 2005), and can even be used to decode coarse categorical distinctions (animal vs. tool) across pictures, sounds, and spoken and written words (Simanova et al. 2014).

Moving further downstream to the perirhinal cortex (PRC), considered to be the most anterior point of the ventral visual pathway (Bussey & Saksida 2002, Murray & Richmond 2001), we find that distinctions between conceptual representations have become even more granular. Bruffaerts and colleagues (2013b) showed that LH PRC response to words correlates with the semantic similarity of those words, with similarity determined by the cosine-distance between 768 dimensional feature vectors, as rated by human subjects. Other studies (Borghesani et al. 2014; Clarke & Tyler 2014; Peelen & Caramazza 2012; Wright et al. 2015) show corroborating evidence, with posterior aspects of ventral visual stream sensitive to perceptual stimulus features, and anterior regions sensitive to the conceptual relationships, as determined by various similarity metrics (Edelman 1998; Edelman & Shahbazi 2012).

Taken together, then, it makes sense that concrete concepts, which have lots of visual features, should activate the vATL regions that show up in concrete contrasts in meta-analyses; these considerations further suggest that manipulating the perceptual `payload' of concrete stimuli could systematically alter the neural response.

With this idea in mind, we want to characterize concrete processing using a strong semantic task, which varies the SM contribution of the stimuli. In particular, we vary the number of modalities that constitute a concept. We want to know how the laterality, anteriority, and superiority of activation in the temporal lobe change as a function of concreteness; and if the triads task can reveal details about concrete semantic processing invisible to weaker tasks.

The neural correlates of concrete semantics have been extensively studied; even so, results of these investigations have proved highly variable. The largest and most well controlled (Binder et al. 2009) as well as the most recent (Wang et al. 2010) meta-analyses both report activation in LH medial structures in the middle of the long axis of the TL, around FG, and PHG, though Binder and colleagues further report RH activation near TPJ/angular gyrus/pMTG. Experiments most similar to ours, such as Sabsevitz et al.

(2005) which also uses triads, or Skipper and Olson (2014) which requires subjects to 'think deeply' about the presented word, show more liberal results, where the medial FG-area extends more laterally and anteriorly (Skipper & Olson 2014) or in all directions, and also bilaterally (Sabsevitz et al. 2005). These results, and dual coding theory, suggest that the general CONC contrast should show bilateral activation, but that activations for CNM should be more bilateral than COM, since more SM features, and feature modalities, should better engage the 'imagistic' system described by the dual code account.

We expect that CNM will show more activation in the ventral TL areas than COM since CNM words include more sensory components, especially visual components, and even though the anterior part of ventral visual stream is not strictly visual, still visual components seem to be a primary influence of activation there. But within this ventral region, how far anterior? A very recent investigation (Hoffman et al. 2015), using a spin-echo pulse-sequence (Embleton et al. 2010; Visser et al. 2010a) designed explicitly to compensate for the signal dropout in ventral ATL due to susceptibility artifacts (Devlin et al. 2000) pushes the involvement just shy of LH TP. Since fMRI research is dominated by gradient-echo imaging due to its superior temporal resolution, it's likely that many studies, especially older ones, lack the signal strength to find activation in this region even when it's there; we should therefore be reluctant to attribute the absence of evidence in this ventral `dead zone' in meta-analytic results to evidence of its absence. While ATL is a primary focus of our investigation, it remains to be seen whether our gradient echo protocol will be sensitive enough to find activation here. Other than this particular area, there's not enough information to be more specific about where exactly in vATL we expect to find activation to our CNM condition, whether ITG, FG, PHG, PRC, etc.

Outside of vATL, we have no prediction about anteriorness because the accounts on the issue are ambiguous. On the one hand, we might predict CNM to be more anterior than COM because CNM words denote real physical entities with more high-level features that span modalities, and the direction increasingly representing feature conjunctions is generally caudal to rostral (Damasio 1989; Visser et al. 2012). Further, the features might find a final convergence in an amodal hub, once considered to be in

TP, the apex of anterior progression (Binney et al. 2012; Damasio 1989). The semantic deficits in patients with SD have been described at length elsewhere in this paper, but an issue especially relevant to the current investigation is that SD patients with ATL damage have recently been shown to have problems learning concepts defined by conjunctions of features (Hoffman et al. 2013). This suggests that CNM stimuli, defined as they are by feature conjunctions, could activate polar regions similar to those that are compromised in SD.

On the other hand, one can also make the opposite case, for the anterior-ness of abstract semantics, since meta-analyses show that abstract semantics activate more anterior regions. Even though both classes of stimuli in the current contrast correspond to sense-able physical quantities (e.g., SCORPION and BUZZING), COM words are less concrete and imageable than are CNM words. If abstract-ness can be considered a matter of degree and not of kind, we might reasonably expect the COM condition to have the more anterior representation.

Abstract-ness should also influence the results on the superior/inferior axis. As described in an earlier section, abstract concepts are considered to be defined linguistically via their relationships to other words; and perhaps for this reason meta-analyses show preferential activation straddling STS, part of the perisylvian language system. If, as described above, abstract-ness is a matter of degree, will our less concrete/less imageable COM stimuli elicit similar superior activation, even though they are still associated with direct physical sensations in the world?

Methods

Stimuli

Based on available feature data, the CNM and COM stimuli differed in mean concreteness, imageability, familiarity, average letters, and Kucera written frequency. They did not differ on other tracked features. The results of feature comparisons between the conditions are summarized in Table 8.

Table 8. Feature differences between CNM and COM

	conc	imag	val	aro	fam	avg let	avg syl	kucera
CNM	607	605	5.2	4.4	500	5.4	1.7	10
COM	499	542	5.1	4.6	531	6	1.7	44
p-val	.0001	.0001			.05	.01		.0001

Image analysis

We tested the univariate results of the CONC-NUM, COM-NUM, CNM-NUM contrasts, as well as the direct comparison of CNM-COM, as described in the triad methods overview. We also used an information searchlight to test the pattern classification ability of the CNM vs. COM conditions, as described in the searchlight methods overview.

Results

Figure 18. CONC>NUM contrast results, LH to RH

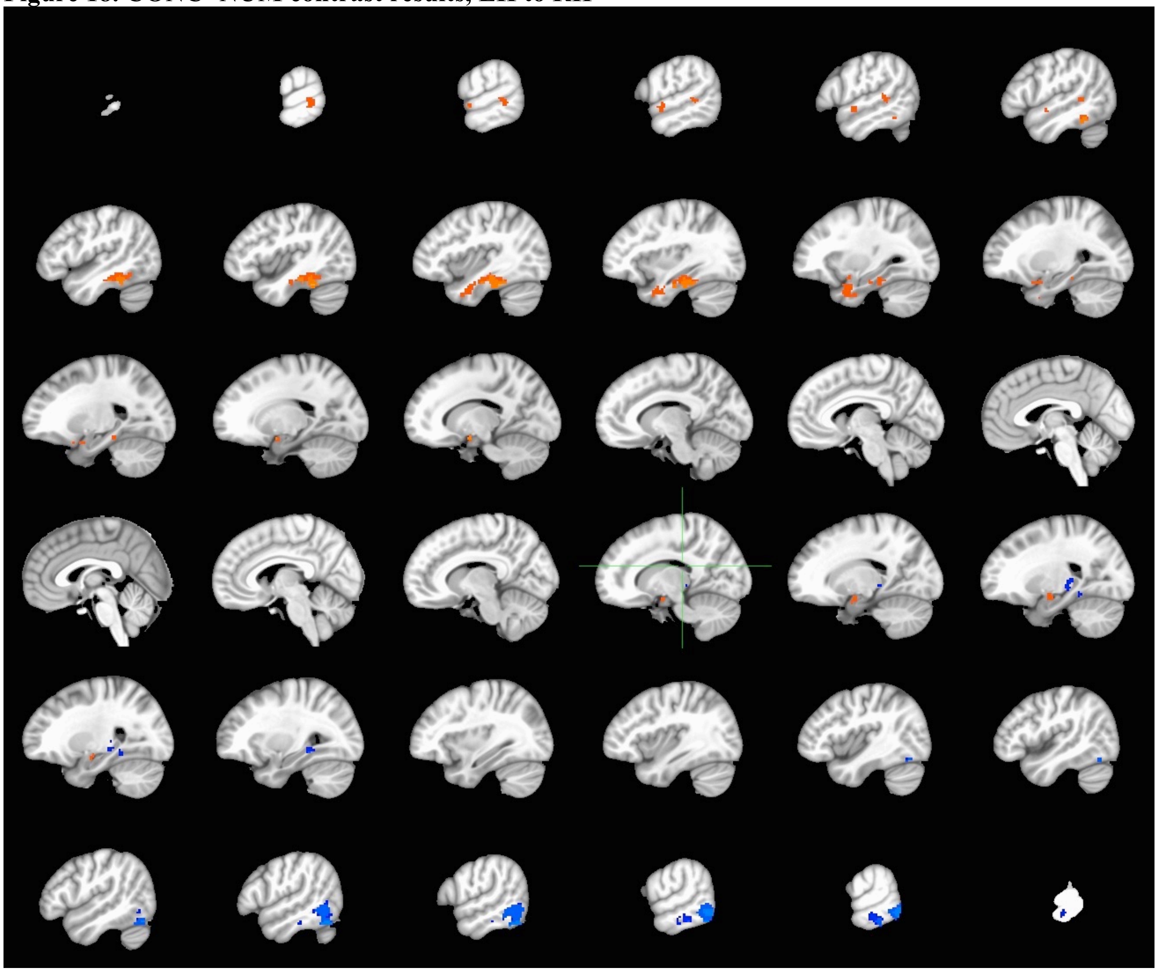


Table 9. CONC vs. NUM

Contrast	Voxels	CM x	CM y	CM z	Peak x	Peak y	Peak z	Structure
conc>num	461	-38.7	-28	-22.2	-40	-40.5	-24.5	LH FG, ITG
	72	-60.6	-40	3.2	-67.5	-40.5	8	LH MTG
	51	-56.7	-2.5	-6.5	-62.5	-0.5	-4.5	LH STG
	35	-22.5	2.8	-19.3	-15	-3	-14.5	LH HPC
	32	19.7	-5.7	-16.4	17.5	-5.5	-14.5	RH HPC
num>conc	417	59.2	-51.4	-12.3	60	-55.5	-22	RH ITG, MTG
	32	21.5	-29.2	-1.3	22.5	-25.5	-4.5	RH HPC
	30	27.8	-39.3	-8.5	30	-38	-9.5	LH PHG

Figure 19. CNM>NUM contrast results, LH to RH

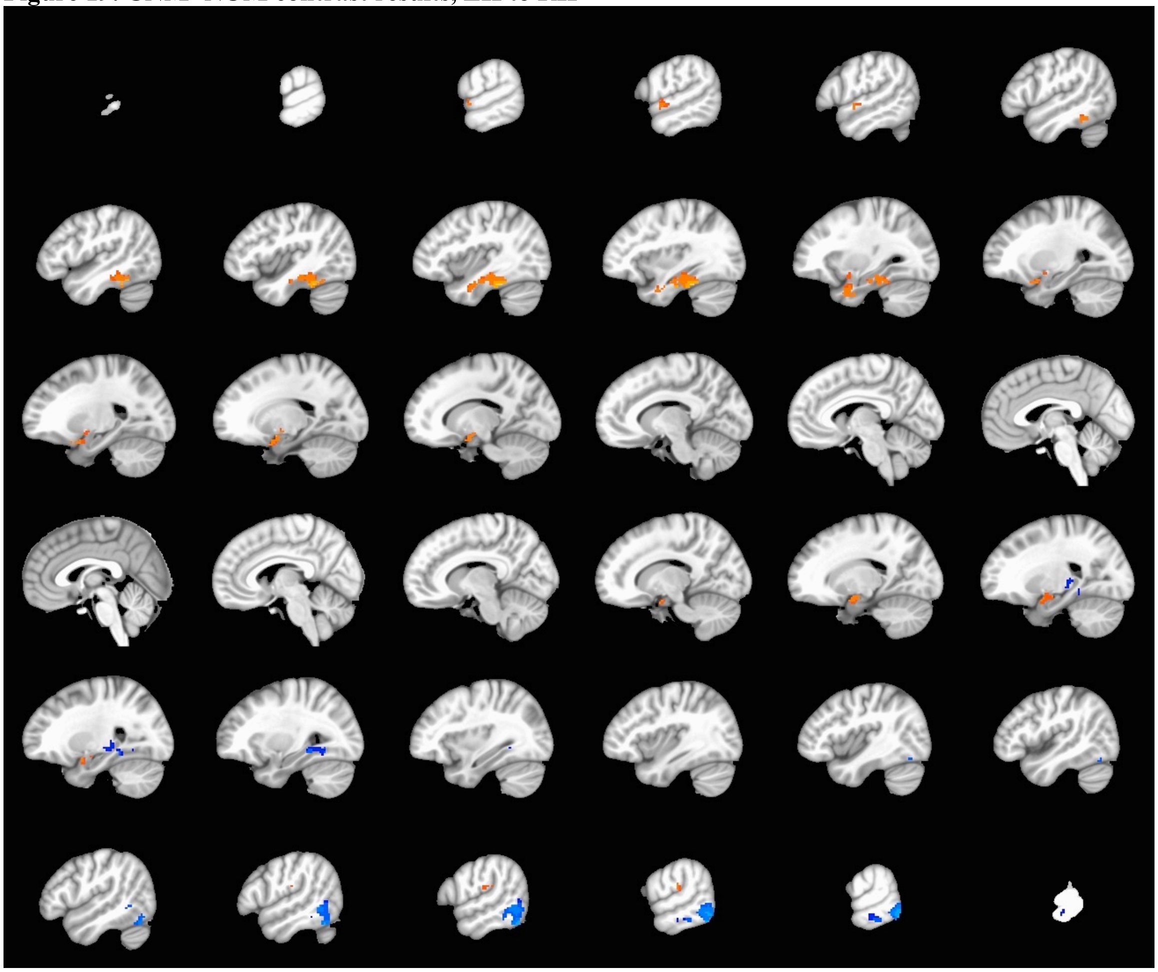


Table 10. CNM vs. NUM

Contrast	Vox	CM x	CM y	CM z	Px	Py	Pz	Structure
cnm>num	365	-38	-34	-20	-38	-38	-24.5	LH FG, PHG
	80	-21	1.	-18	-18	-1	-14.5	LH AMY, HPC, PHG
	70	-32	1	-31	-30	2	-32	LH FG, PHG, MedTP
	62	21	-3	-18	18	-6	-15	RH AMY, HPC, PHG
	31	-58	-3	-2	-60	-1	-5	LH STG
	24	60	-22	20	60	-21	21	RH SMG
num>cnm	295	59	-54	-11	60	-56	-22	RH ITG, MTG
	73	29	-46	-8	30	-38	-9.5	RH FG, PHG
	44	66	-27	-15	68	-28	-22	RH ITG, MTG
	26	24	-29	-2	23	-26	-5	RH HPC

Figure 20. COM>NUM contrast results, LH

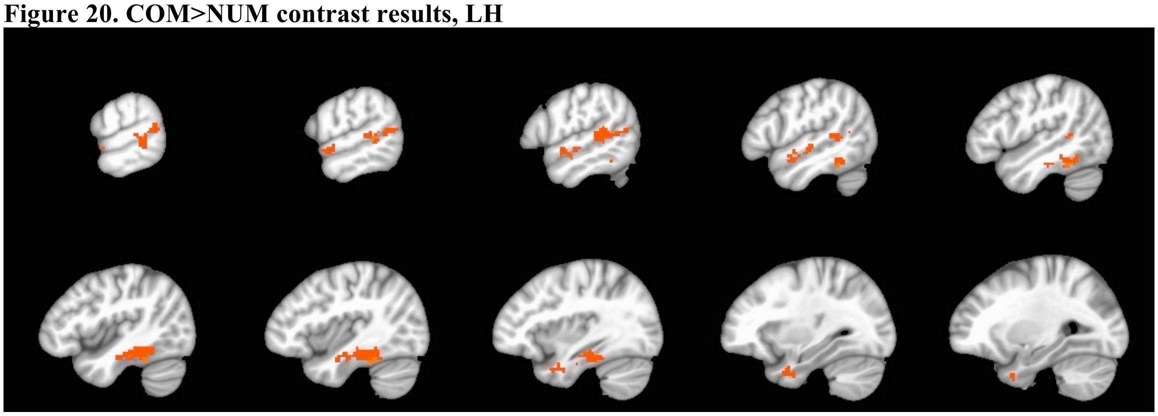


Figure 21. COM>NUM contrast results, axial view, with crosshairs in RH reversed-direction (NUM>COM) pMTG cluster

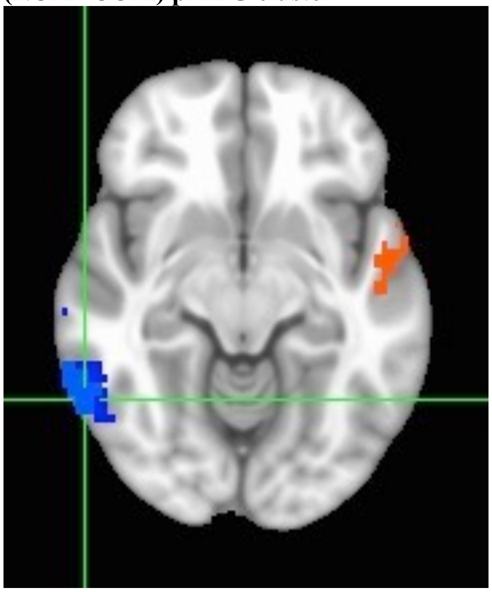


Table 11. COM vs. NUM

Contrast	Voxels	CM x	CM y	CM z	Px	Py	Pz	Structure
num>com	384	59	-52	-13	60	-56	-22	RH ITG, MTG
com>num	337	-41	-30	-21	-40	-41	-25	LH FG, ITG
	235	-60	-44	7	-68	-41	8	LH MTG, STG
	96	-55	-5	-9	-63	-1	-5	LH STG

Figure 22. CNM>COM contrast results (205 voxels) with crosshairs in LH reversed-direction (COM>CNM) pMTG cluster

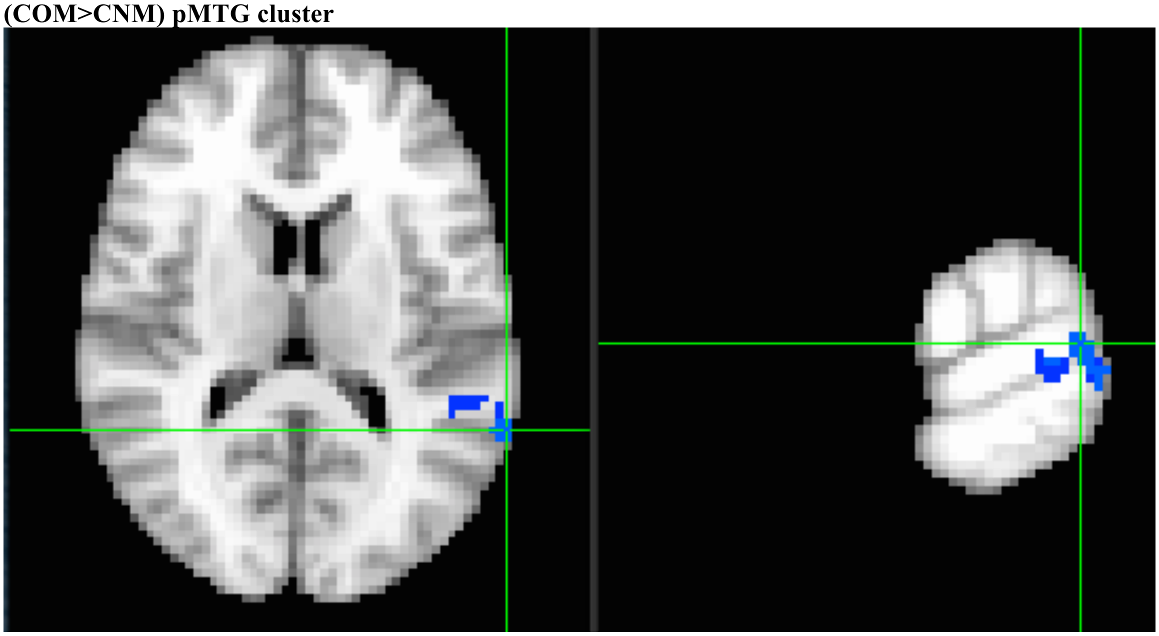


Figure 23. CNM>COM contrast results (87 voxels) with crosshairs in LH FG cluster

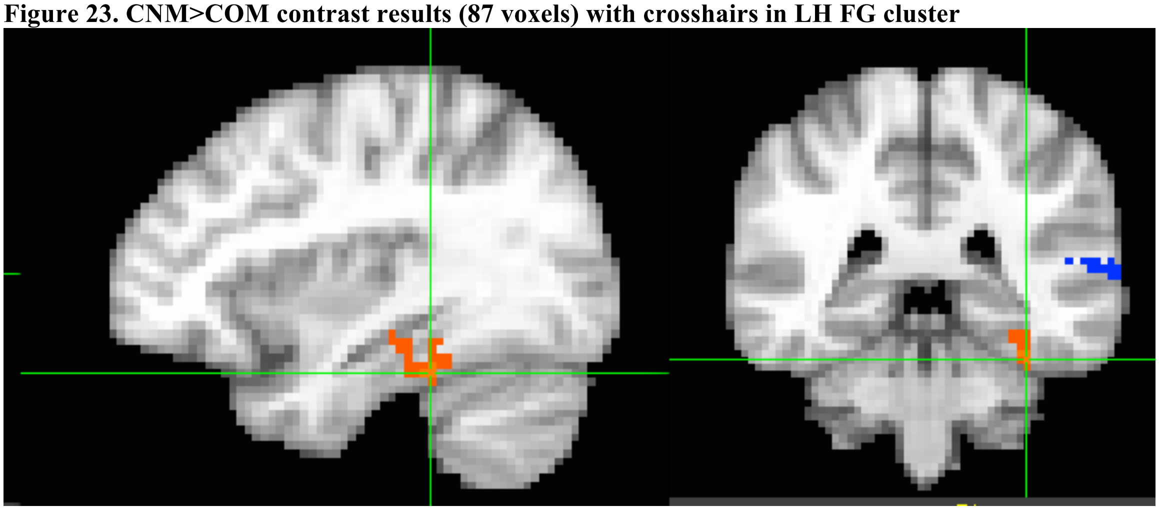


Table 12. CNM vs. COM

Contrast	Vox	CM x	CM y	CM z	Px	Py	Pz	Structure
com>cnm	219	-59	-47	8	-65	-51	13	LH STG, MTG
	93	-32	-34	-18	-35	-38	-25	LH FG

Discussion

Concrete multi-modality vs. number-word and concrete one-modality vs. number-word

The CONC>NUM contrast includes a minimal RH activation in TL, in hippocampus, but in general it is heavily left-lateralized. However, when the concrete conditions are broken apart and considered separately, the RH contribution of the more concrete of the two (CNM) grows considerably: the hippocampal contribution spreads to PHG, as predicted, and an additional cluster in supramarginal gyrus appears that had been absent in the aggregate CONC>NUM contrast.

These findings can be considered ambivalent evidence for dual-coding theory. Technically, as Paivio's (1991) theory predicts, concrete stimuli have bilateral representation. Further, in this contrast, the more concrete CNM stimuli have a stronger RH presence than the less concrete COM stimuli. This might suggest a general rule of thumb, in which bilateral involvement occurs on a concreteness gradient, except that our ABS>NUM results, reported in an earlier section, put the lie to the notion, as that contrast produces a larger cluster in RH than does the CNM>NUM contrast. It is possible that the larger RH ABS response is due to the greater statistical power for that condition, since ABS is aggregated across both HSS and LSS conditions, whereas the CNM stands alone. Still, it seems reasonable that a concrete advantage based on bilateral neural recruitment should not require such apologetics.

Contrary to its more concrete brethren, the activations produced by the COM>NUM contrast is restricted to LH, as predicted. The results for this contrast appear, upon inspection, more similar to results from ABS>NUM than to CNM>NUM. Since the COM triads are significantly less concrete and imageable than are the CNM triads, the similarity to the results from the abstract condition is perhaps not surprising, though the exact implications of this are not clear. For instance, if the current trend is to be believed, and more abstract stimuli elicit Royal Road processing (straddling STS, and approaching TP) then how abstract is abstract enough? And other than simply not being concrete — a notion expressed by the usual feature ratings in terms of the highly-correlated `concreteness' and `imageability' — what does it mean to be abstract? We will return to this topic later.

While abstractness appears to modulate the extent of laterality in TL to some degree, its results on anteriority are less clear. Both the COM>NUM and CNM>NUM contrasts produce comparable anterior activation in LH, reaching y=10 (MNI, LPI). However, the ABS>NUM activation reported in the earlier section reaches significantly further rostrally, to y=25. Any prospective explanation for anterior progression must be more complicated than a simple linear relationship to concreteness or imageability.

The large clusters in medial/ventral TL are as expected, since this region is commonly activated using concrete semantic stimuli, presumably owing to its down-stream position in the ventral visual stream. However, the sheer quantity of activation here is remarkable compared to existing results from the literature, suggesting once again the efficacy of the triads task in producing a strong semantic response. It seems likely that the activation in this region would be even larger except for the susceptibility artifacts, since the most ventral aspect of ITG that is bare of activation has the lowest signal of the entire acquired volume due to dropout and distortion, as discussed in (Devlin 2000) and shown in our SNR image.

Concrete multi-modality vs. concrete one-modality

The larger of the two clusters, in pMTG, is more active for COM than CNM. This region has been implicated in semantic control (e.g., Jefferies 2013; Whitney et al. 2011a, 2011b), which can be broadly characterized as the process by which contextual elements are assembled to make a concept interpretable during semantic processing. With this definition in mind, the pMTG results make sense: the COM stimuli are less imageable and less concrete — idiomatically, they are more abstract — and so, like abstract words generally, appear in more diverse settings than do words that correspond to specific objects in the world, like our CNM stimuli. Consequently, COM words require higher levels of semantic control to facilitate their interpretation (Hoffman et al. 2011).

The single CNM>COM cluster shows that an increased number of concrete features leads to an activation in FG. One explanation for this could be that this area codes for features common to the things in CNM stimuli. Even though CNM stimuli include words that are very different in appearance, behavior, and human-relevance (ANT vs. BUFFALO vs. BANANA) they are nonetheless similar on a number of scales when compared with COM stimuli. The CNM>COM FG activation could encode one of these coarse dimensions, such as a "living/non-living" distinction, or even a "physical object/not-physical-object" distinction (e.g., Connolly et al. 2012; Mahon & Caramazza 2009; Simanova et al. 2014). The other explanation is that this CNM>COM activation could reflect the operation of a semantic hub.

There are a couple of ways we might identify a hub. We described the first way in the overview: according to the canonical hub model (Rogers et al. 2004, 2006) we would expect that regions within a hub would be more active during the CNM condition, since a hub would be required to reconstitute more modalities — e.g., the shape, color, movement, and emotional reaction to a SCORPION — whereas the COM condition would only require re-instantiation of features from a single modality, e.g., BUZZING. However, the region revealed in the CNM>COM results is not in the vATL region identified by (Binney et al. 2010; Mion et al. 2010), weakening the case for its candidacy.

However, it's also possible that instead of a simple mean-activation difference in the region, the hub is comparably active when reconstituting the many modalities in CNM stimuli, or the single modality for the COM stimuli, and it is the pattern of activation within the hub, rather than its mean level of activation, that distinguishes the two conditions.

Mass-univariate analysis is not sensitive enough to untangle cases like this, since significance is determined on a per-voxel level. In contrast, by considering the patterns encoded within groups of voxels it is possible to not only detect region-wide patterns, but even say something specific about how they are generated. For instance, using multi-voxel techniques another lab found evidence for compositional representations for concrete nouns, and that the representation of the concept "boy" is composed of the combined representations of the concepts for "male" and "young" (Baron & Osherson

2011) in an ATL ROI anterior to our CNM>COM results. This is a relationship between stimulus and neural response that univariate analysis could not have found.

With these caveats in mind, we believed that it might be possible to use multivariate techniques to find areas that were sensitive to representational differences between CNM and COM not present in the results reported in the last section. To test this idea, we ran an information searchlight (Kriegeskorte et al. 2006) using an SVM classifier to distinguish between the CNM vs. COM conditions. The results we hope for from this searchlight investigation are especially those we predicted, but did not see, from the univariate analysis. For instance, it's possible that a more anterior vATL region like those described in (Binney et al. 2010; Mion et al. 2010) really is a semantic hub, but our univariate analysis could not detect activity there. In fact, considering the prevalence of representational gradients in the ventral stream (from simple visual features in posterior regions to conceptual representations in anterior regions, Bruffaerts et al. 2013a; Carlson et al. 2014a; or big/small animate/inanimate objects, Sha et al. 2014) we might expect above-chance classification results anywhere anterior to those reported in the univariate results, as patterns of high-level features built from the outputs of modal areas. This would give us greater confidence in interpreting our results as evidence of a CDZ/amodal hub and not simply as greater activation due to more or more complex visual features.

In addition to the factors motivating the searchlight analysis, we note that an amodal hub should, by definition, be active for all kinds of semantic representations. Though the hub is not usually considered in the context of abstract semantics, its proponents do not disclaim a role for it in abstract semantic processing. Therefore, in a different attempt to flush the amodal hub out of hiding we'll make a superconjunction from the results of our various semantic contrasts (ABS, CNM, COM, NOV) vs. the non-semantic number-words (NUM) condition. The reason for using the conjunction of the individual results (ABS>NUM ^ CNM>NUM ^ …) instead of a single, univariate contrast ((ABS+CNM+COM+…)>NUM) is so a single condition that is highly evocative of a certain ROI cannot, through the strength of its activation, pick up the slack for a condition that does _not_ evoke that ROI. Our assumption is that an ROI that serves as a hub should activate to a semantic vs. non-semantic contrast across all conditions; if a given voxel is not activated for some particular condition, then that voxel should be removed from candidacy as a putative member of an amodal hub.

Results (searchlight)

The following images show the spotlight results. We used a spotlight of radius 3 with a linear SVM classifier. Since we were interested in finding areas that could be classified at greater than chance accuracy, but that could not be identified using the univariate techniques described earlier, the spotlight results were masked by the previously reported univariate results. Additionally, we did not want to identify voxels associated with difficulty modulation, so we masked the spotlight results by the difficulty (as determined by reaction time) regressors for each of the COM and CNM conditions. The results below therefore are the voxels that show greater than chance searchlight performance in distinguishing the COM and CNM conditions, but that don't appear in any univariate results associated with those conditions.

For easier comparison, the following image shows the spotlight results (filtered, as described above) in the right-hand panel, and the univariate results (including difficulty regressors) for CNM vs. COM in the left-hand panel.

Figure 24. Searchlight results (335 voxels), CNM vs. COM contrast, with crosshairs in LH pMTG. In univariate analysis the proximate cluster was for COM>CNM.

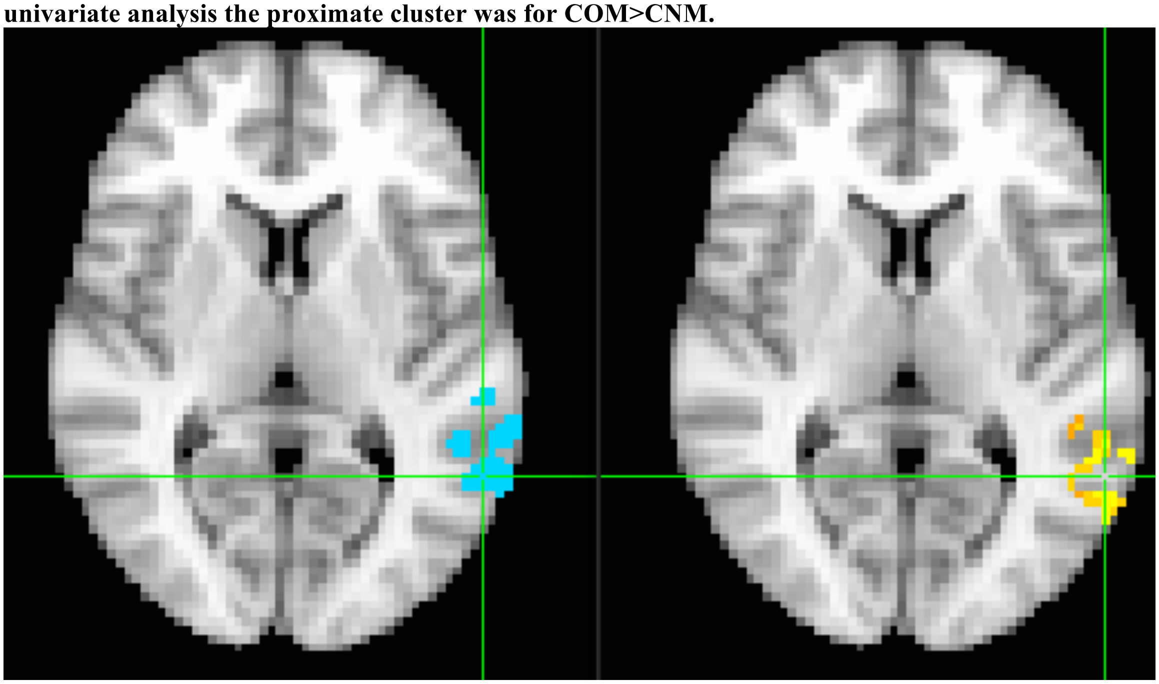


Figure 25. Searchlight results (62 voxels), CNM vs. COM contrast, with crosshairs in LH FG. In univariate analysis the proximate cluster was for CNM>COM.

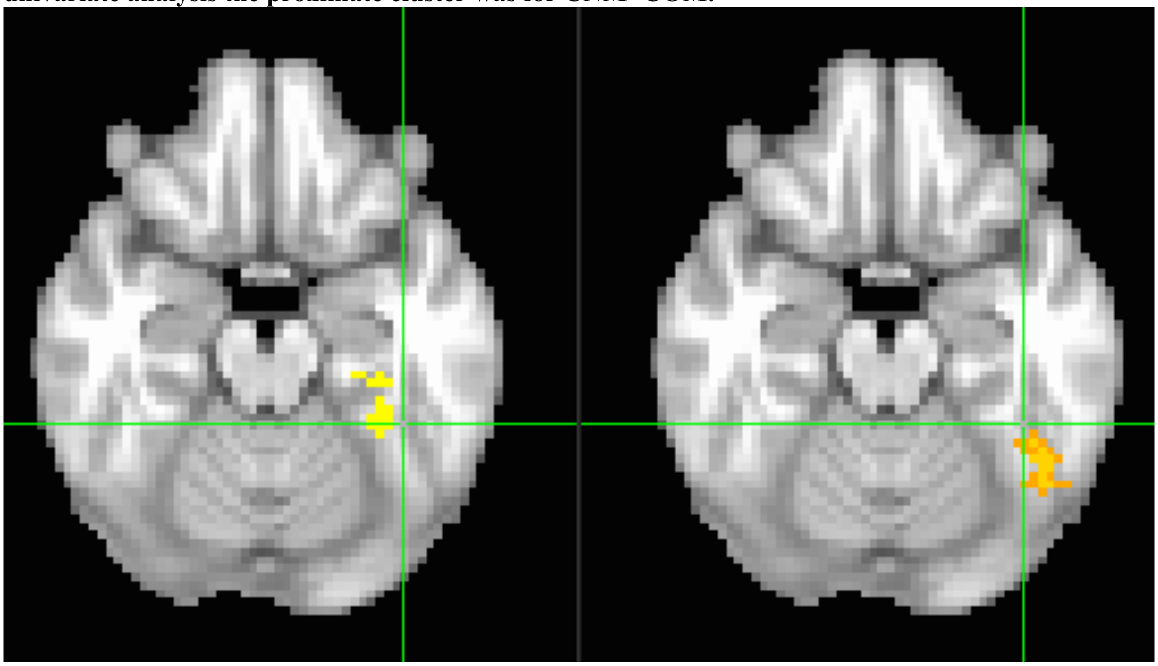


Table 13. Searchlight results of CNM vs. COM

Contrast	Vox	CM x	CM y	CM z	Px	Py	Pz	Structure
~com>cnm	335	-58	-51	7	-65	-51	6	LH STG, MTG
~cnm>com	62	-45	-55	-19	-45	-53	-20	LH FG

Discussion

The largest cluster identified by the searchlight, in pMTG, is closely interwoven with the results of our univariate analysis in that region. This intermingling makes it difficult to propose that the searchlight activations indicate pattern information in this ROI. However, we might take as contrary evidence the results of an experiment from Fairhall & Caramazza (2013), which found that MVPA analysis of this same pMTG region contained supra-modal representations. One could potentially unite their results with ours by positing that the region contains multivariate representations (their results) that are also detectable by single-voxel mean differences between the classes (our results). However, as discussed already, this region in pMTG is commonly activated by tasks with increased semantic-control demands. So while it's possible that pMTG encodes pattern information about the CNM and COM conditions, and the patterns themselves include diagnostic features whose mean activations allow some voxels to show activation differences in univariate analysis, the simpler explanation is that no such pattern information exists, and that our searchlights are picking up mean activation differences "bleeding into" proximate searchlight results, which can occur when a single diagnostic voxel is shared between all searchlights within the searchlight radius (Etzel et al. 2013). Fairhall & Caramazza's ability to decode the region, and our inability to do so, could be due to the clearer categorical boundaries defined by their stimuli (pictures of or words naming fruit, tools, clothes, mammals, and birds), which is consistent with impressive decoding results in other experiments that use stimuli whose features vary systematically on perceptual features (e.g., Mitchell et al. 2008).

On the other hand, the relationship between the second FG searchlight cluster and the corresponding cluster from the univariate analysis is not confounded by colocation, since the searchlight results do not overlap with the univariate results within the searchlight radius. Considering the proximity of the searchlight cluster (posterior and lateral) to the comparable univariate cluster (anterior and medial) in FG, it seems reasonable to suggest that patterns of feature conjunctions that will eventually differentiate the CNM and COM semantic classes are already available in posterior aspects of temporal lobe, and that the development of conceptual representation begins earlier and more laterally in the processing stream than univariate analysis can detect, at least in our paradigm.

Since from a certain vantage the CNM/COM distinction is very basic — does the word denote an object in the world, or not? — it's not surprising that even a very posterior region could be sensitive to it, though of course the region could be activated for a number of reasons, since the CNM vs. COM contrast satisfies a number of categorical distinctions simultaneously (Grill-Spector & Weiner, 2014), and other multivariate techniques have shown considerable category-sensitivity even in very posterior aspects of TL (Connolly et al. 2012; Haxby et al. 2011).

The attentive reader will note that this explanation is the opposite from the one given above, with regard to searchlight results in pMTG. The question then becomes whether it is possible that the COM/CNM distinction can be too muddled to be distinguishable in pMTG and yet possibly be distinguished in FG. While we cannot say for sure, we will note two things. First, a medial-to-lateral gradient has been proposed as meaningful in TL, in addition to the usual caudal-to-rostral gradient (Visser et al. 2012), so differences in representational characteristics at different lateral depths do not seem unreasonable. Second, the alternative interpretation (that pMTG is sensitive to both univariate and multivariate representations) is actually more permissive than our proposed explanation.

Turning next to our second method for hub-detection, the results of the super-conjunction, which show an active region in FG/ITG are somewhat surprising. Though they have not been considered to be strictly visual regions for some time, nonetheless to find FG/ITG activated for triads of all conditions, including abstract triads with no direct visual or physical manifestations, is noteworthy. Moreover, unlike the results from our univariate analyses, this region does fall within the ROI identified by Mion et al. (2010) as correlating significantly with semantic impairment in SD patients. The image below shows the superconjunction in the top row, followed by the Mion ROI (yellow and dark blue) in the bottom row.

Figure 26. Results for superconjunction -- voxels common to reported ABS>NUM, CONC>NUM, NOV>NUM contrasts, with crosshairs in LH FG/ITG

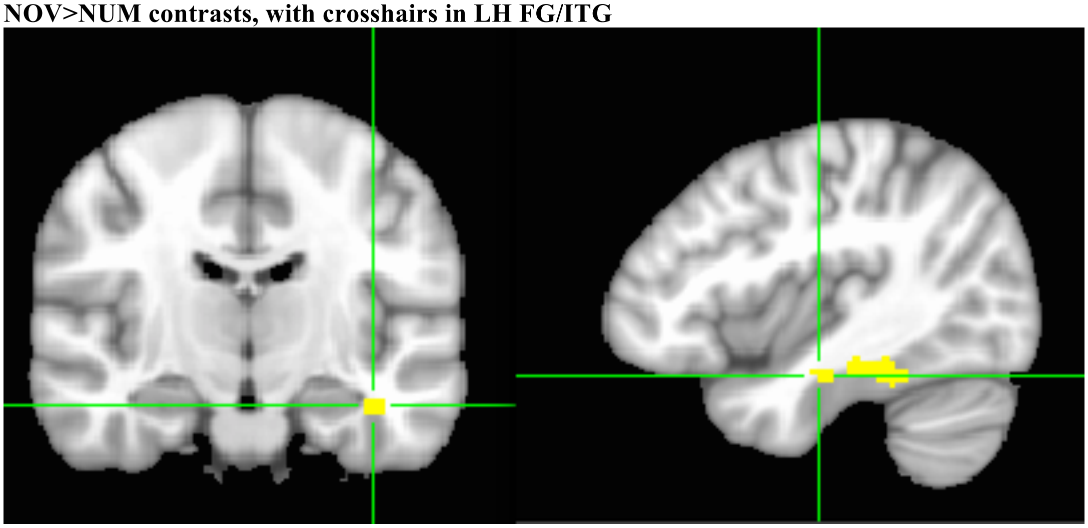


Figure 27. Results from Mion et al. (2010) where yellow ROI indicates area in FG maximally correlated with semantic performance in SD patients and neurotypicals.

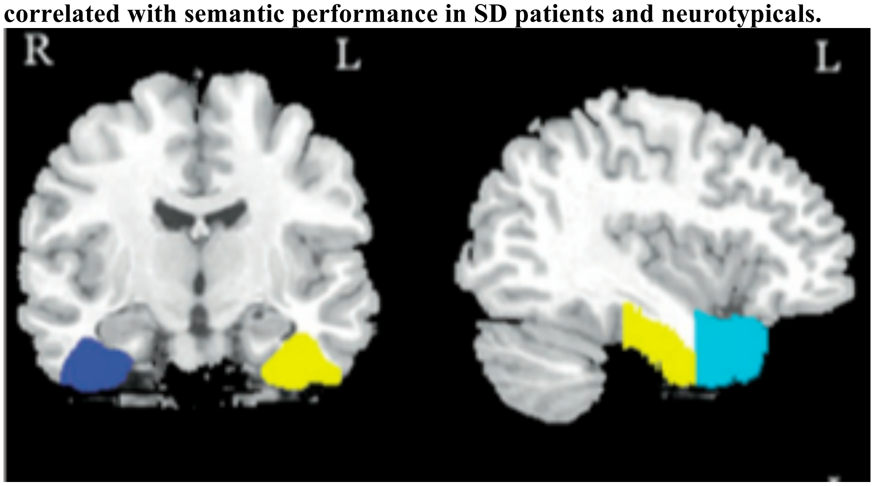


Table 14. Superconjunction cluster

Contrast	Vox	CM x	CM y	CM z	Px	Py	Pz	Structure
all	73	-42	-36	-18	-40	-41	-25	LH FG, ITG

So the superconjunction — the area commonly activated across all semantic contrasts — falls within the part of ventral ATL currently believed (by proponents of that theory) to be the location of the amodal hub. What are to we make of this result, when compared with our other univariate and multivariate results on this topic?

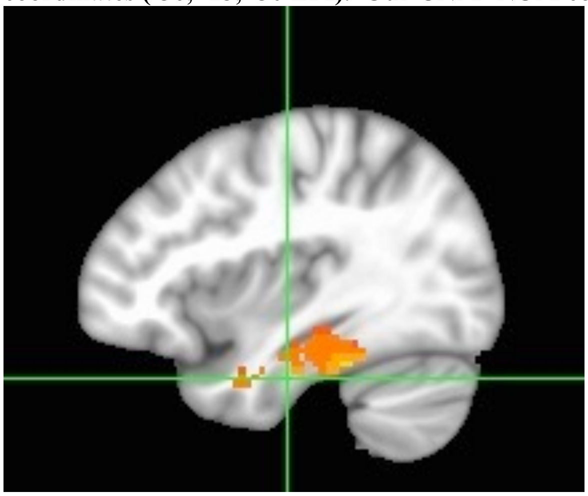
Considering the logic that led to the proposal of an amodal semantic hub — the fact that generalized damage to ATL resulted in systematic semantic erosion across all representational and access modalities (reviewed in Patterson et al. 2007), as well as more recent and subtler evidence regarding compromised acquisition of concepts defined by feature conjunctions (Hoffman et al. 2013) — the superconjunction seems a more reasonable hub-detection test than the CNM>COM contrast, since the superconjunction assumes less about how the hub aggregates modal spokes (e.g., Rogers et al. 2004, 2006; Ueno et al. 2011). An amodal hub ought to manifest in semantic processing across all flavors of semantics, and that is what we find here. The fact that the manifested region is gated by activity to semantic content largely void of explicit SM features (our abstract conditions) makes the result both stronger and more surprising.

However, these results are not perfectly in accord with the most recent projections of the amodal hub's location.

Binney and colleagues (2010) posited a proximate region in vATL at (-36, -15, -30 LPI, MNI) as the location of the hub. In a series of three experiments on SD patients and healthy controls, they showed that a) patients with SD had tissue damage in this ROI, b) that non-patient controls showed activation in the same ROI during semantic tasks, and c) rTMS centered on this region (or rather, to the lateral surface most proximate to it) reproduced the same pattern of SD deficits in healthy controls, while preserving the same non-semantic performance that was preserved in SD patients.

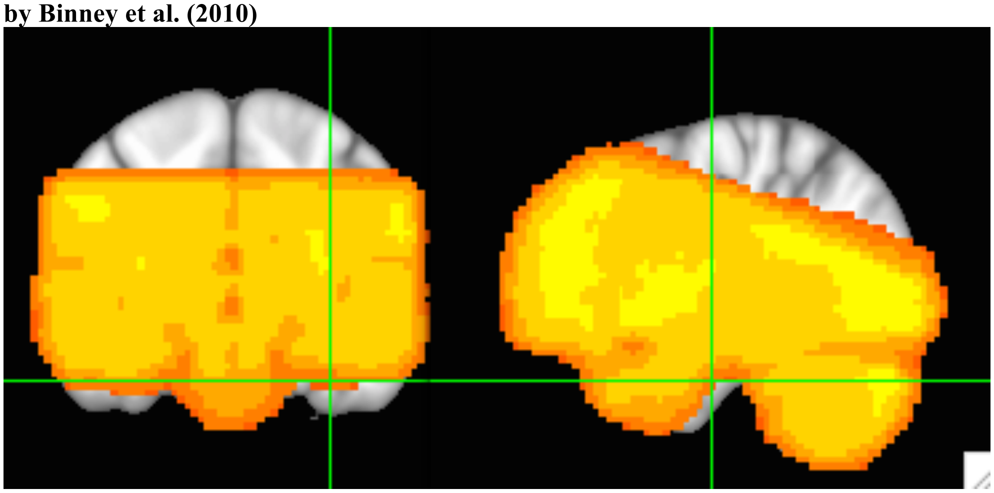
The results of our superconjunction do not include this point; however, they generally surround it. Moreover, since the stimuli used in the experimental tasks by Binney and colleagues (2010) — and indeed, by every SD battery of which we are aware — are concrete, it is instructive to examine this location in relation to our CNM>NUM contrast. The crosshairs in the following figure center on those coordinates.

Figure 28. Crosshairs at candidate semantic hub location reported by Binney et al. (2010) at MNI coordinates (-36, -15, -30 LPI). Our CNM>NUM contrast activation is in warm colors.



As one can observe, the ROI identified by Binney and colleagues is closely surrounded by voxels activated by our most concrete semantic condition. Crucially, the vATL region missing from our results corresponds almost exactly to regions of sub-threshold SNR, as reported in our methods section. For ease of reference, the SNR image is reproduced here, in which voxels with SNR < 40 appear grey, consistent with the SNR threshold that has been used as a cutoff in several recent studies (Hoffman et al. 2015; Tyler et al. 2013) that have tailored their protocols to improve signal in this region.

Figure 29. SNR, reproduced from methods overview. Crosshairs at site of amodal hub as proposed by Binney et al. (2010)



These low-SNR voxels are entirely absent from results in all our contrasts. Even with modern imaging protocols, equipment, and distortion-correction techniques, this vATL region is problematic in gradient-echo protocols like ours. Visser and colleagues

(2010) and Embleton and colleagues (2010) described a spin-echo variant that improves SNR in this region, at the cost of reduced statistical power due to other tradeoffs.

The results from our experiment are consistent with the existence of a semantic hub in vATL, but they are not capable of making a stronger statement, which requires affirmative answers to two diagnostic questions. The first question is: does semantic processing require this region's involvement to process diverse conceptual types? Our results seem to indicate that the answer to this question is "yes," at least in LH. Though the amodal hub theory posits that the hub is bilateral, it is possible that differential connection strength between hemispherical structures biases results, such that LH is dominant during normal processing (Schapiro et al. 2013; Ueno et al. 2011).

The second diagnostic question is: if this region (and only this region) is compromised, how does that alter the brain's ability to process diverse types of concepts when that conceptual processing is assayed through pictures, words, spoken language, etc.? The best answers to this question, to date, are the combined results from Mion and colleagues (2010) and Binney and colleagues (2010), though the generalized cortical damage in SD patients, and the inability to create precisely-targeted `virtual lesions' (especially to more medial areas) with the application of rTMS, necessarily limits the definitiveness of these results, or any others that depend on the same methodologies. Recent work using micro-electrode arrays for recording and stimulation of patients during pre-surgical diagnostics offers additional confirmatory evidence, though sample sizes are small and results are harder to interpret (Shimotake et al. 2014).

In summary, while they cannot be conclusive on the issue, our results are consistent with the position that vATL hosts an amodal semantic hub.

Abstract and concrete

Overview

In earlier sections we've contrasted concrete and abstract semantics separately, with activations for each found against our non-semantic number-word condition. Now with those results providing interpretative context, we want to emphasize the distinction between these two classes directly by comparing abstract and concrete features.

A good deal of work exists contrasting abstract and concrete semantics. Based on aforementioned meta-analyses by Wang and colleagues (2010) and Binder and colleagues (2009) we would predict activation for abstract concepts exclusively in LH ATL/TP, and concrete activations in medial temporal (FG and proximate) and lateral temporal-parietal structures, in both hemispheres. These are generic predictions informed by the cacophony of empirical work (as summarized in the oft-cited meta-analyses), and also by the broad tenets of dual coding theory (Paivio 1991) with which those broad results are, unsurprisingly, consistent.

However, based on studies that adopted deep semantic processing tasks, and specifically triads tasks, that are the most comparable to our own approach, we would expect to depart significantly from the least common denominators reported above, and predict more extensive activation for abstract concepts in LH, either caudal from the TP along STS extending continuously nearly to occipital lobe (Sabsevitz et al. 2005), or as a secondary cluster straddling the second and third thirds of MTG (Noppeney & Price 2004). The appearance of a cluster of this size would make a strong statement about the efficacy of the triads task in evoking stronger and more extensive processing than other semantic tasks, and implicate regions in semantic processing that are often not considered.

Methods

Stimuli

Based on available feature data, the ABS and CONC stimuli differed in all tracked categories, with the exception of average number of letters. The results of feature comparisons between the conditions are summarized in the following table.

Table 15. Feature differences between ABS and CONC

	conc	imag	val	aro	fam	avg let	avg syl	kucera
ABS	344	413	5.6	5.2	537	5.7	1.9	84
CONC	560	578	5.2	4.5	513	5.7	1.7	27
p-val	.0001	.0001	.01	.0001	.0001		.001	.0001

Image analysis

We tested the univariate results of the ABS-CONC contrast, as described in the triad methods overview.

Results

Figure 30. Results for ABS-CON contrast, LH to RH

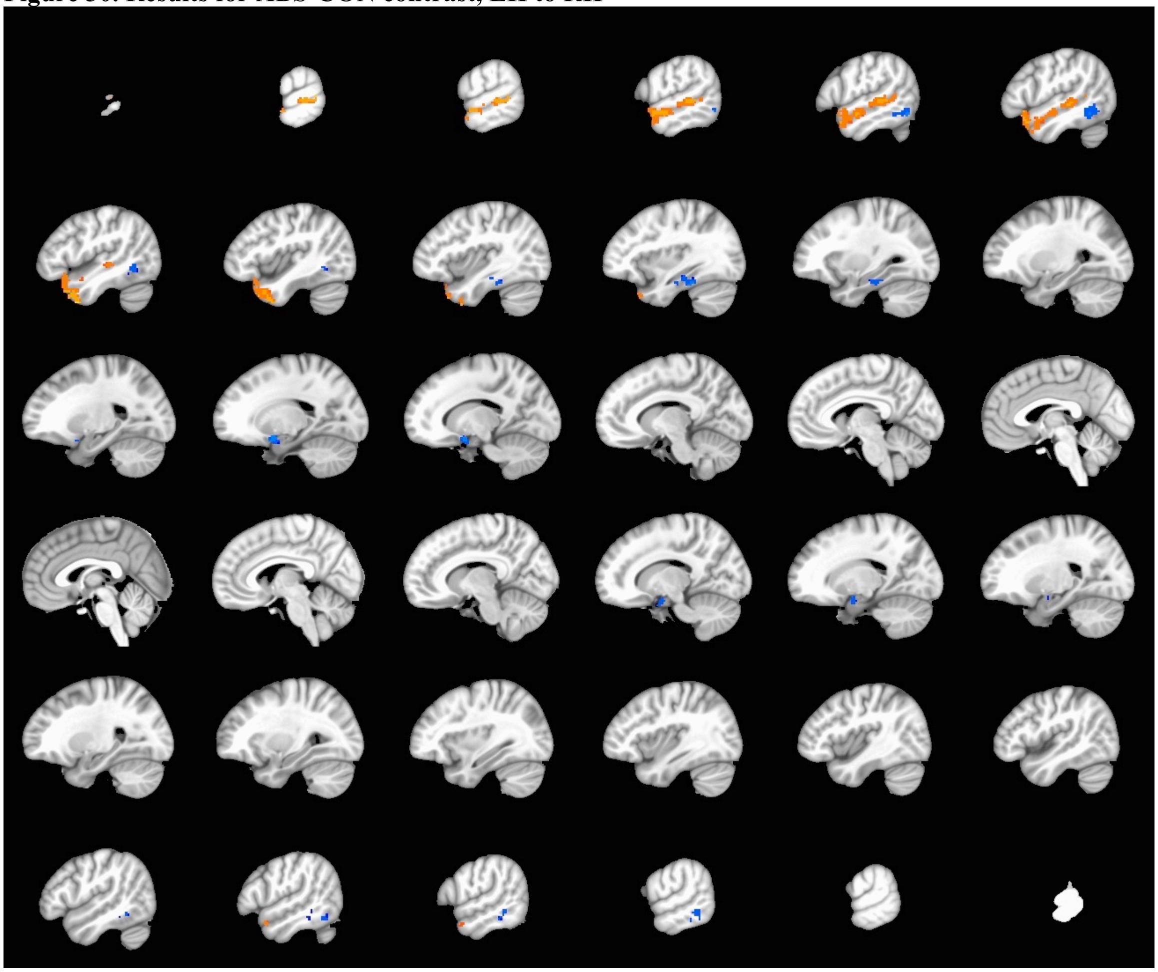


Table 16. ABS vs. CONC

Contrast	Voxels	CM x	CM y	CM z	Px	Py	Pz	Structure
abs>conc	497	-50	7	-22	-48	7	-45	LH ITG, TP, MedTP, MTG, STS, STG
	249	-57	-34	2	-68	-46	8	LH STG, STS, MTG
	21	57	7	-22	55	10	-22	RH MedTP, MTG
conc>abs	127	-50	-56	-10	-55	-63	-15	LH ITG,
	72	-33	-30	-21	-35	-36	-25	LH FG,
	55	60	-41	-12	63	-46	-17	RH ITG
	46	-18	3	-18	-18	2	-17	LH AMY, HPC, PHG
	27	18	-2	-19	20	2	-20	RH AMY, HPC, PHG
	21	53	-54	-14	55	-53	-17	RH ITG

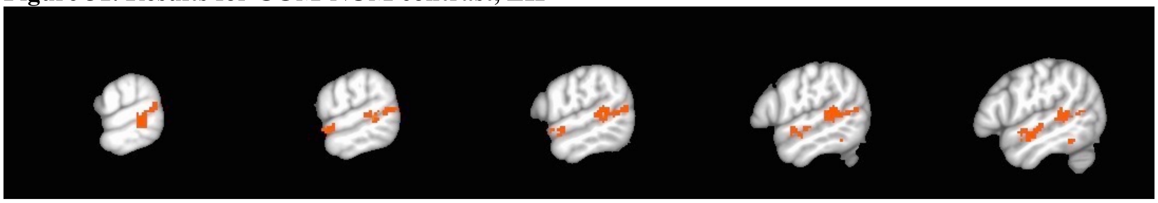
Discussion

Contrasting our abstract triads with a semantic (concrete) baseline does not significantly attenuate bilateral results compared to a non-semantic (number-word) baseline: our results are overwhelmingly left-lateralized, but are not restricted to that hemisphere, and the particular regions favored by abstract triads in the ABS>NUM contrast still appear. Particularly, LH TP is strongly activated for abstract contrasts but not for concrete contrasts. This is strong confirmatory evidence for accounts that hypothesize a caudal/rostral abstraction gradient (e.g., Binney et al. 2012; Damasio 1989). On the other side of the contrast, the regions implicated in processing concrete stimuli in our CONC>NUM contrast (namely, FG and PHG) continue to appear when the concrete word stimuli are instead contrasted with abstract words. It's clear that, when compared directly, the abstract and concrete triads do indeed have quite different signatures.

The stronger contrast also did not eliminate the extensive RR activation sweeping from the rostral to caudal extremes of temporal lobe. Earlier we posited that this pattern of activation was evidence of the triads task's success in accomplishing its existential purpose of eliciting deep semantic processing. The continued existence of robust activation throughout this region when using a more stringent baseline lends evidence to this interpretation, although its inconsistency with a much larger body of extant work continues to be unsettling. The inconsistency persists even when we restrict comparisons to stronger semantic tasks. For example, consider the difference in extent between results like ours and those from Sabsevitz and colleagues (2005), both of which reveal activation that are extensive and continuous in STG through the long axis of the temporal lobe, vs. the results of Noppeney and Price (2004), which feature a cluster in temporal pole, a cluster in posterior STG, and an absence in the middle that is contrastingly filled in both our results and those from Sabsevitz and colleagues.

At first blush this difference between these results from studies using the triads task seems inexplicable — all three experiments use the same methodology, the same contrast, and share some of the same stimuli — but upon further examination we believe we have an explanation that accounts for the variation. The candidate explanation hinges on the fact that the 'concrete' words that make up the Noppeney & Price triads, which they contrast with their abstract words, include many of our own COM words (or rather, our COM words include many of theirs). When this concrete COM sub-condition is contrasted with the non-semantic NUM condition, we see the following results ($p < .001$, $\alpha < .01$), reproduced from the earlier section on concrete semantics.

Figure 31. Results for COM-NUM contrast, LH



This COM>NUM contrast shows a number of active clusters along the RR, including gaps of activation that are missing from Noppeney & Price's results. It appears likely, then, that the `questionable concreteness' of their concrete stimuli led to results from this region being `subtracted out' from the regions they ultimately reported in their abstract-concrete contrast. This is a specific example of a more general phenomenon that has been proposed to explain "missing results" in a number of studies of semantic cognition (Visser et al. 2010). Further, the reduced concreteness of our COM stimuli, as compared to our CNM stimuli, could explain the absence of predicted RH activation in FG: if this region is involved in representing concrete concepts, then reduced concreteness could eliminate the `spillover' into the non-dominant hemisphere in service of concrete processing, consistent with our findings and with the dual coding account (Paivio 1991) as it is broadly construed.

With these caveats in mind, the results from both external sources that used the triads task to test abstract and concrete semantics (Noppeney & Price 2004; Sabsevitz et al. 2005) fall into accordance with our own, as do the results from a recent study that used a 'deep' lexical decision task (Skipper & Olson 2014) that achieved comparably broad activation in RR. It would appear that for demanding semantic tasks using abstract stimuli, results like ours are replicable and consistent.

Novel triads

Overview

As described earlier, a key component in our motivation for choosing the triads task is because it required the subject to deeply engage with the semantics of the constituent words. This makes the triads task more demanding and realistic than more commonly-used tasks like lexical decision, which sometimes do not produce activation (e.g., Kiehl et al. 1999), and which can potentially confuse the investigation of semantic cognition.

However, the semantic elaboration required by the triads task is limited by the existence of a correct result: once the subject finds the appropriate feature or feature set along which the words in the triad can be put into alignment with each other for the sake of comparison, the process is finished.

The novel triads are an attempt to push the semantic system even harder by introducing a triad variant in which a correct answer did not exist, so that semantic exploration would be both more thorough and less constrained.

In so doing we aimed to reveal the neural correlates of a semantic process that is not often addressed, namely, the creative construction of meaning out of atoms where there is no obvious meaning to unite them. This is important because semantic processing does not occur in isolation; it is frequently embarked upon in the service of cognitive pursuits that involve integrating knowledge from diverse domains. Often this process of integration is exploratory and iterative: real life does not always present a person with an obvious correct answer, even to simple problems.

This creative function of the novel triads task calls to mind a sub-field of semantics investigation called conceptual combination (CC). In CC research, experimental interest centers around how a conceptual object is constructed out of primitive objects. An example of this is adjectival modification, where the concepts RED and COUCH, each of which are meaningful in isolation, are combined to form a new concept (RED COUCH) that reflects aspects of each (Baron et al. 2010; Baron & Osherson 2011; Bemis et al. 2011; 2013).

The details of how exactly this occurs are not known. But the idea seems useful as an analogy for the process by which an answer for a novel triad could be constructed. As an example, consider the novel triad (LEGEND, PLAN, TOAD). Since the words in this triad lack an obvious basis for mutual comparison, one might propose an algorithm in which the elements are considered pairwise as conceptual combination candidates. If LEGEND<=>PLAN coheres (forms a sensible emergent concept) better than does LEGEND<=>TOAD then the subject chooses PLAN as the word more similar to LEGEND; otherwise, he chooses TOAD.

This assumes a great deal, obviously, and could be grossly wrong in its particulars. But the general point remains: making a decision using NOV stimuli could require the construction of new, original (and temporary) concepts out of separate pieces (see Thagard & Stewart 2011 for a computational model based on a similar idea). If this is the case, then we might expect that regions supporting conceptual combination will also be active when processing NOV triads. Based on EEG and fMRI evidence cited above, and related fMRI work on MVPA decoding of concepts based on the combined responses of more perceptually-dominated regions (Coutanche & Thompson-Schill 2014) this suggests activation in the first third of the TL, up to and including TP.

Aside from this specific prediction, our more general prediction for this contrast is that the activation will amount to a superset of that produced by all the other contrasts. Since novel triads include both concrete and abstract semantics, they should activate all the regions present for exclusively abstract and concrete contrasts. In fact, we hypothesize that the activation for the NOV triads will be even more extensive, owing to the increased semantic requirements posed by the stimuli and task, as described above. We expect that this will be an ideal task to activate TP, especially the middle convolution, which anatomical and connectivity evidence suggest to be the most modality general (Binney et al. 2012; Ding et al. 2009; Pascual et al. 2013; Visser et al. 2012). If processing the NOV triads requires the most semantic convergence, and the convergence that is required spans modality and abstraction, then polar activity should also be highest.

Methods

Stimuli

Based on available feature data, the NOV and ABS stimuli differed in mean concreteness, imageability, familiarity, and arousal. They did not differ on other tracked features. The results of feature comparisons between the conditions are summarized in the following table.

Table 17. Feature differences between ABS and NOV

	conc	imag	val	aro	fam	avg let	avg syl	kucera
ABS	344	413	5.6	5.2	537	5.7	1.9	84
NOV	432	473	5.5	4.9	517	5.7	1.9	59
p-val	.0001	.0001		.05	.01			

Results

Novel vs. number-word

Figure 32. Results for NOV-NUM contrast, LH to RH.

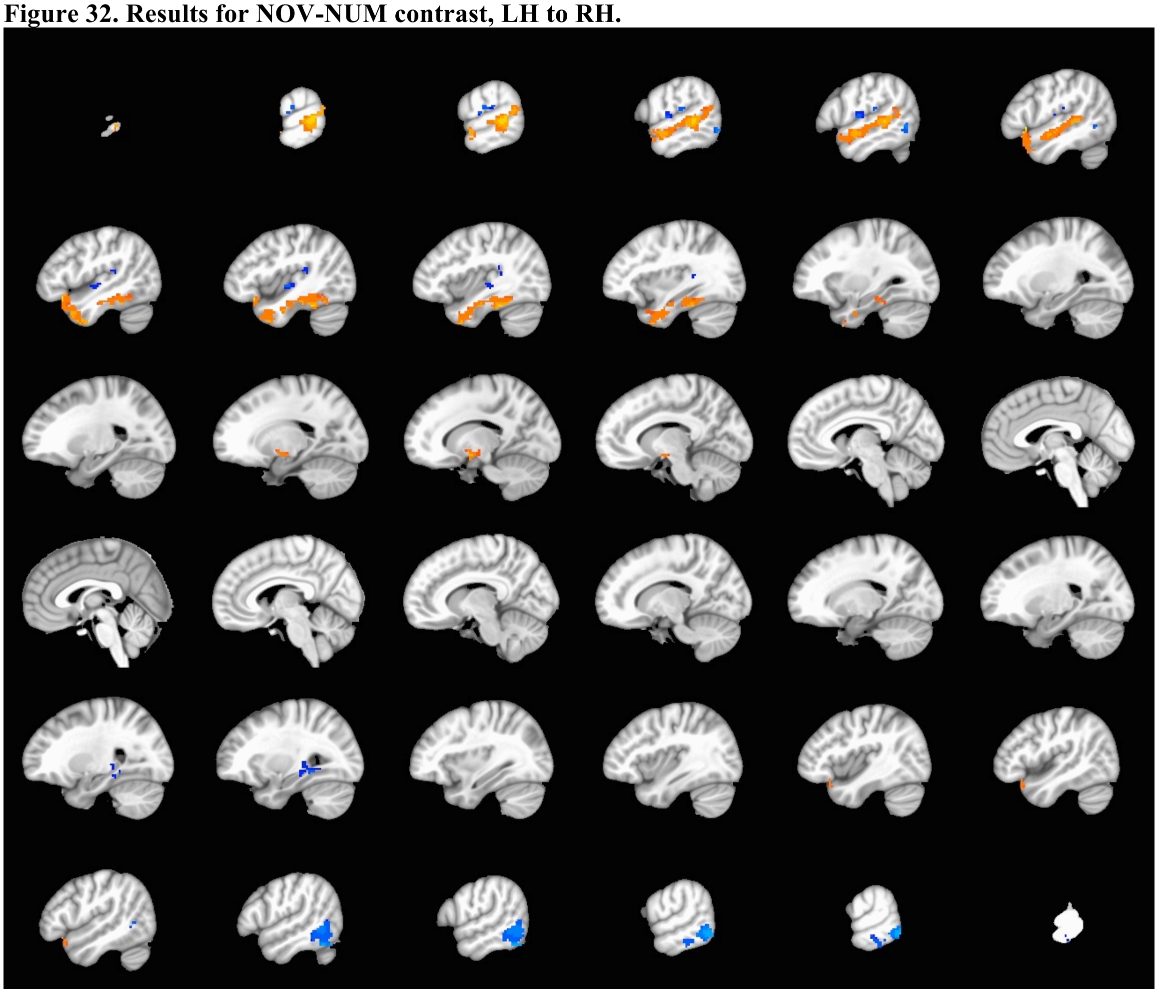


Table 18. NOV vs. NUM

Contrast	Voxels	CM x	CM y	CM z	Px	Py	Pz	Structure
nov>num	729	-58	-29	-1	-68	-43	8	LH STS, MTG, STG
	681	-41	-11	-26	-53	20	-5	LH FG, PHG, ITG, TP, MedTP
	52	-15	-7	-11	-15	-3	-12	LH HPC, AMY
	29	47	23	-20	50	25	-15	RH TP
num>nov	306	59	-53	-10	60	-53	-22	RH ITG
	58	28	-37	-6	30	-38	-10	RH PHG, HPC
	46	-56	-11	10	-65	-13	13	LH STG, HschG
	43	64	-31	-18	65	-33	-20	RH ITG
	37	-42	-17	-2	-43	-13	-2	RH STG
	34	-41	-35	15	-48	-33	16	LH STG
	31	-60	-24	18	-65	-18	18	LH SMG
	30	-54	-62	-5	-53	-61	-2	LH MTG

Abstract vs. novel

Figure 33. Results for ABS-NOV contrast, LH to RH

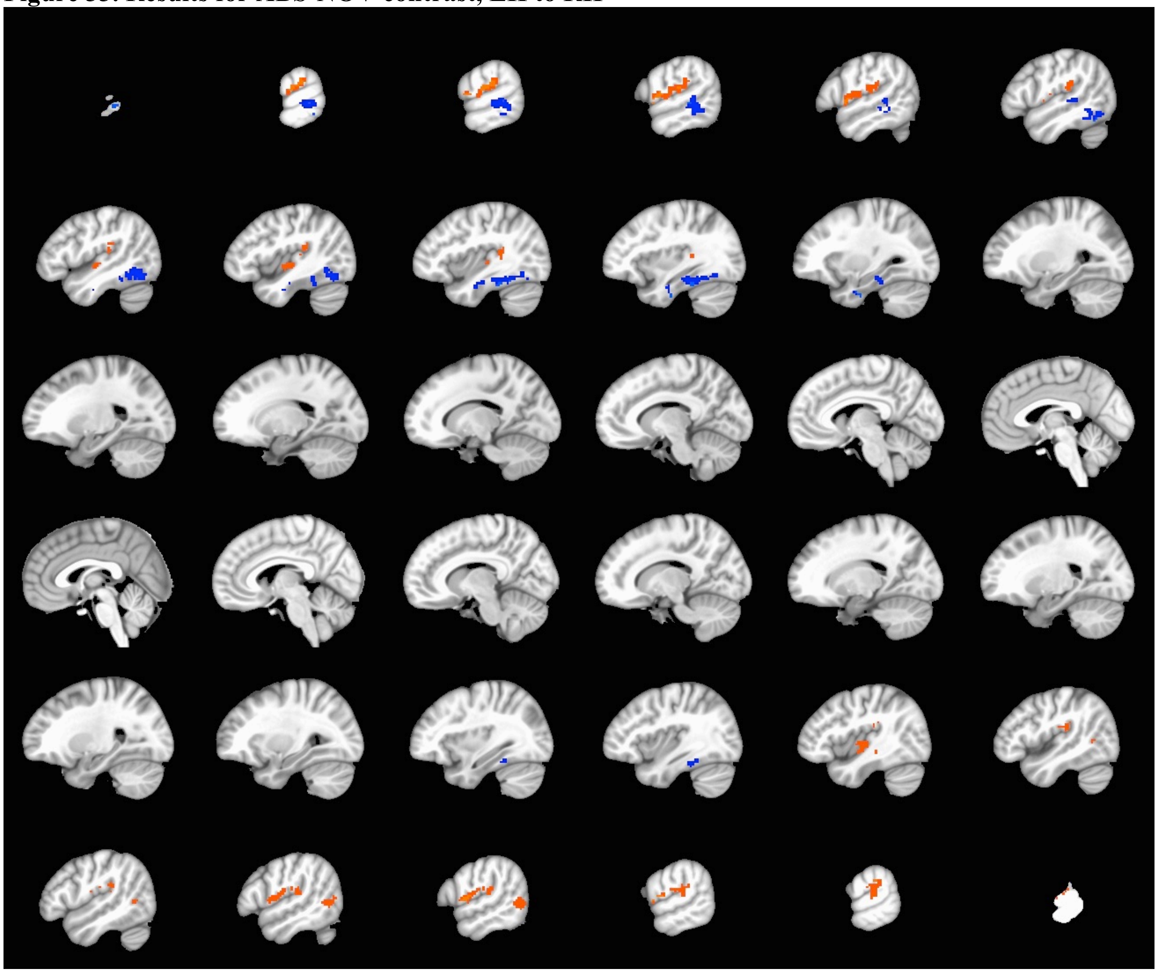


Table 19. ABS vs. NOV

Contrast	Voxels	CM x	CM y	CM z	Px	Py	Pz	Structure
abs>nov	341	-57	-18	16	-65	-21	21	LH STG, SMG, HschG,
	272	60	-15	16	63	7	6	RH STG, SMG
	71	55	-60	3	58	-66	3	RH MTG
	48	41	-15	-3	40	-16	1	RH INS
	44	-42	-14	-2	-43	-13	-2	LH STG, INS
nov>abs	315	-41	-50	-16	-48	-61	-20	LH IT, FG,
	209	-61	-38	-1	-68	-43	-12	LH MTG
	45	-35	-10	-30	-30	-11	-35	LH FG
	22	37	-39	-20	38	-41	-20	RH FG

Discussion

The ability of NOV>NUM to activate LH TP is impressive. No other triads contrast matches it: though other abstract contrasts (ABS>NUM and ABS>CON) also drive the polar region, the reach of their activation is not as extensive as that for NOV>NUM, particularly in their dorsal/ventral extent; indeed, no other contrast or task achieves such ventral activation. This suggests that whatever unites these different contrasts in driving TP, the novel triads have the most of it. It's noteworthy, however, that even though the activation for NOV>NUM is more extensive than that for ABS>NUM, the contrast between NOV and ABS shows no polar activity, suggesting that ABS>NUM results are sub-threshold and the whole TP region is likely involved.

The Royal Road activation continues the precedent set in the other abstract triad conditions. The posterior origin of the RR, the LH pMTG, is explicable in terms of semantic control. The deactivation in RH pMTG is due to the processing of numerosity, as described in an earlier section. One puzzler is the partial de-activation in the most dorsal portion of STG with respect to the number-word contrast. It is difficult to know what to make of this.

The STG deactivation in the NOV condition continues in even more extreme form in the ABS>NOV contrast. In fact, the activation advantage of the ABS vs. the NOV condition in STG is the dominant feature of this contrast. Considering how forcefully NOV activates TP, it's curious that results in STG should be systematically attenuated compared to ABS.

One interpretation for this finding might be that though the cognitive operations required to perform the triads task are more intensive for NOV vs. ABS triads, the NOV condition nonetheless features less abstract processing, since there are fewer abstract words per triad in the NOV condition. This would suggest that the abstract-ness `recedes' ventrally from the dorsal limits of STG. This is in keeping with the secondary gradient (in addition to the familiar caudal —> rostral gradient) described by Binney et al. (2012).

The implication, taken in context with the results from other triads contrasts, is that the RR, or at least its superior aspect, is related either to the representation or manipulation of abstract semantics, or else to auxiliary processing demands that accompany abstract semantics. We might propose that the same logic might be forwarded to explain the ABS dominance of activations observed in both LH and RH hippocampus: perhaps HPC activity corresponds to the amount of contextual support, or contextual resolution, needed to support a decision with more abstract content? It's also possible that hippocampal activation reflects the increased relational processing demands that would presumably be required by abstract words, since abstract words are more characterized by their relationships to other words than are concrete words (Markman & Stilwell 2001; Vigliocco et al. 2009). Both these explanations sound sensible, except for the results of the ABS>CONC contrast described in an earlier section, where bilateral HPC was more active for CONC than for ABS triads, a finding more in line with dual-code theory, or at least its more obvious interpretation.

Another inexplicable aspect of the current results is the scattered deactivation along STG for NOV>NUM; and the lack of comparable deactivation in the same region for CONC>NUM. It's not clear why NOV>NUM should be less active everywhere in dorsal STG than ABS>NUM, and also less active (if only slightly) in scattered parts of dorsal STG than CONC>NUM, especially if the region seems to be recruited for some correlate of abstract processing.

General discussion

Overview

The most noteworthy results of our various contrasts are centered on what we have been calling the Royal Road, a region running along STS caudally to rostrally all the way to TP, and spreading into both neighboring gyri.

RR activity manifests in all activations that involve abstract triads. Generally speaking, the more abstract the content, the more superior the activation. This is best illustrated by the ABS>NUM contrast, which activates the most superior aspects of STG; and the difference between the COM>NUM and the CNM>NUM triads, where the former, relatively abstract, contrast activates portions of the RR, and the latter, thoroughly concrete, contrast does not.

Though RR activation is absent from most results investigating abstract semantics in the wider literature, as we noted earlier, we see comparable activity in experiments that use an intense semantic task (e.g., Sabsevitz et al. 2005; Skipper & Olson, 2014). So our results seem to be quite consistent with a broader trend. But what is that trend?

"Royal Road" activation is not due to emotion or social information

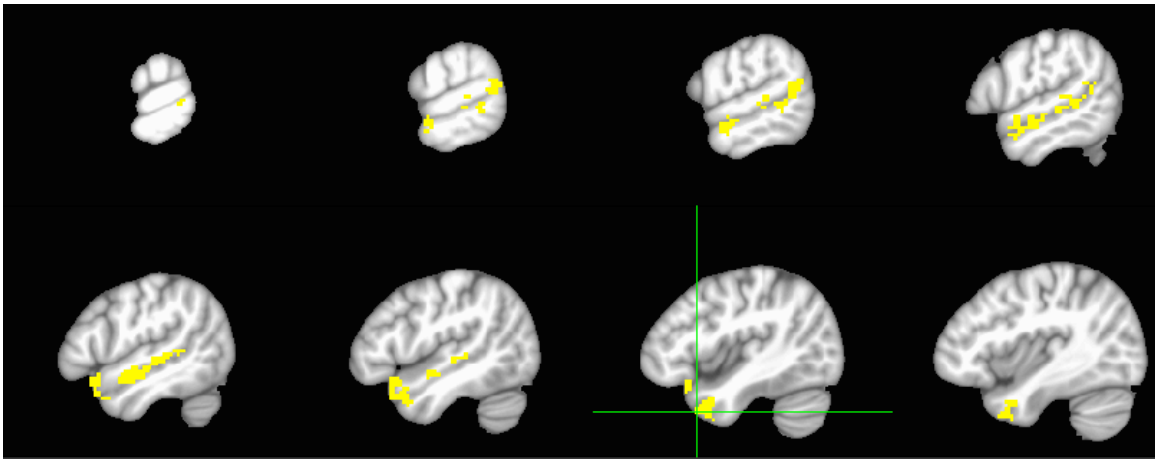
One possible proposal is that, even though the RR activation appears correlated to the abstractness of the stimuli, in reality it is other, latent factors within the stimuli that are responsible. In the course of this paper we have investigated several candidate latent factors at some length. The social information hypothesis (Olson et al. 2013) posits that ATL responds preferentially to social content. A more granular account (Kousta et al. 2009, 2011; Vigliocco et al. 2014; reviewed in Olson et al. 2007) posits that, either as part of social processing, or independently of it, it is emotional content that drives ATL activation. Both of these accounts can be justified with compelling anatomical and functional connectivity evidence (von der Heide et al. 2013; Fan et al. 2013; Pascual et al. 2013) suggesting that semantic representations are mixed with motivational / valuational inputs from frontal regions.

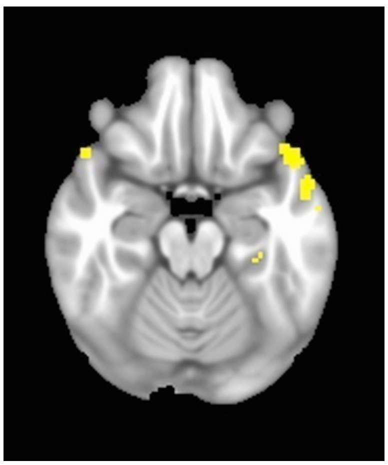
The only problem with the explanatory power of these accounts is that they appear to have nothing at all to do with our own findings. While the case for ATL involvement in social processing is particularly compelling, our results emphasize quite strongly the obvious fact that social information is not a unitary construct; and further stress the importance of task-salience in interpreting the importance of stimulus features. In our experiment, neither social information nor emotional information was of direct or salient relevance to the semantic decision required by the triads task, or (in the case of the emotional localizer) to the repetition detection task. It is possible that this is the central explanation for why neither social nor emotional content activated RR regions in our abstract contrasts. This absence would be in accordance with our fundamental assumption that semantic processing is not latent in the stimuli that are processed; rather it reflects the particular interface between the task and its inputs (Lebois et al. 2014). So while social and emotional content might robustly drive the semantic system, they weren't doing it in our experiment. The RR activation came from somewhere else.

"Royal Road" activation is noteworthy; but common in sentence processing

Though it is rare in experiments using individual words, RR activity is common in experiments that use sentence stimuli (e.g., Friederici 2012; Marr 2011).
To compare our triads results with this larger body of literature, we ran a sentence localizer (see general methods section) that contrasted the response to sentences (SENT) vs. non-word `jabberwocky sentences' (JABBER) following Fedorenko and colleagues (2010). The following images show the conjunction of our NOV>NUM results, and this SENT>JABBER contrast. The first image shows LH, with crosshairs positioned at the furthest anterior position, with y=15. The second axial image shows an axial view revealing common RH activation in the TP across our NOV>NUM triads task and the SENT>JABBER contrast.

Figure 34. Conjunction between NOV>NUM and SENT>JABBER activation results.





We can see that results from a triads contrast and the sentence localizer produce a large overlap in RR. Considering that the results from the triads task are noteworthy in their extensiveness, when compared to results of ABS vs. CONC meta-analyses (Binder et al. 2009; Wang et al. 2010) we are compelled to ask what element is common to triads and sentences that could lead to this common activated region?

We propose that the crucial element is that both are about integrating structure.

Integration proposed as the common operation of triads and sentences

Royal Road activations are familiar in the sentence processing literature. With regard to the anterior portion, a variety of results suggest the reason for the activation is that activity in ATL and TP scales up as more syntactic or semantic information must be integrated into a situation model (Zwaan et al. 1995, 1998) that encodes the sentence's collective meaning. For instance, (Brennan & Pylkkänen, 2010; Humphries et al., 2006) showed that syntactic processing of complete sentences engaged the region more than did the sentence's components alone; Pallier et al. (2011) showed that ATL and anterior portions of STS show a BOLD response corresponding to the size of the syntactic structure that is being integrated; and in a task where subjects listened to a 12-minute chunk of Alice in Wonderland, activity in LH temporal pole activated in relation to the amount of syntactic structure built in response to the receipt of each word (Brennan et al. 2012).

However, much must be done to process a sentence, and it is difficult to know which particular processing component is giving rise to the effect. We might explore the same idea in a reduced context by examining results in the conceptual combination literature, which explores the emergent meaning of word combinations without explicit syntactic rules.

For instance, Baron and colleagues (2010) and Baron and Osherson (2011) have shown that LH ATL encodes conceptual combinations for both human referents (BOY = MALE + YOUNG) and for terms denoting animals (CHICKEN = FARM + BIRD) such that the voxel pattern for the composite (BOY) correlates more highly with the product of the voxel patterns for the constituents (MALE + YOUNG) than it does with other patterns lacking the semantic relationship. A series of studies from the Pylkkänen lab **(**Bemis et al. 2011, 2013; Pylkkänen et al. 2014; Westerlund et al. 2015; Westerlund & Pylkkänen, 2014**)** also show ATL involvement in conceptual combination tasks, although the spatial specificity is less clear since MEG studies are less precise and the region under investigation included more temporal regions of larger extent (i.e., BA38, BA20, BA21).

Additional evidence from ATL damage in SD (Hoffman et al. 2014) showed that patients were compromised in their ability to learn configurations of features; and patients with unilateral ATL damage due to aneurism or tumor resection were unable to integrate facial features or configurations or dots (Olson et al. 2014). These are recent instances of a more venerable literature in which ATL damage leads to an erosion of holistic perceptual abilities (e.g., Kimura 1963; Lansdell, 1968; Meier & French, 1965).

These literatures accord with the hypothesis that the ATL is a CDZ that binds together disparate featural and configural aspects into coherent conceptual combinations; and that the triads task may induce a combination of constituent feature bundles for the sake of mutual inspection and comparison to support the ultimate semantic decision. This compositional process would thus be a less structured version of the integration that occurs in the course of sentence comprehension, where the disparate atoms in the sentence are combined to form a coherent, over-arching meaning.

Moving out of the ATL, STG is associated with processing both auditory stimuli and words (Spitsyna et al. 2006). These representations are thought to become more abstract as activation migrates ventrally toward MTG as part of the `dual gradient' caudal > rostral + lateral migration from modality-specific zones (Binder et al. 2009; Binder & Desai 2011; Visser et al. 2012) where they can access converging semantic information from concrete entities arising out of the ventral visual pathway.

However, if this is true then it is noteworthy that abstract triads, and not concrete triads, drive RR. For instance, both abstract and concrete concepts would seem to require integration, and to make comparable phonological demands. With these operations seemingly in common, why should the difference between abstract and concrete triads be so stark?

The special integration challenge of abstract semantics

Integrating abstract features

How abstract concepts are represented is a matter of heated debate. Abstract concepts have been shown to have more substantial emotional (Kousta et al. 2011; Vigliocco et al. 2014) and social components (Borghi et al. 2013) than do concrete concepts. Crucially, abstract concepts also are more heavily defined by the situations in which they occur (Barsalou 2003), their relationships to other concepts (Gentner 1981), and by the roles their constituent elements require (Markman & Stillwell, 2001). Because of this relational and compositional structure, abstract concepts are more deeply hierarchical and complex than are concrete concepts (Barsalou & Wiemer-Hastings 2005).

These additional conceptual aspects impose additional integrative requirements when compared against concrete concepts that do not include these same aspects, or that include fewer of them. A particular challenge is how to represent the relational and role-based `features' of abstract semantics.

For instance, imagine a video of a lion chasing a gazelle; and another video from a Heider & Simmel-style animation where a red square is `chasing' a blue triangle. What is the definition of `chase' that would allow an observer to classify both examples as instances of `chasing' both easily and automatically?

One might imagine the various ways in which an intelligent observer could represent these encounters by decomposing them into a series of simple measurements, so as to capture their essences. One straightforward representation might be a 2d plot for each entity mapping out its position vs. time. Another could be a plot of the distance between the two entities, which would rise and fall as the predator neared the prey and the prey evaded. Yet another might be a vector representing gaze direction — such an indicator might be important in some circumstances to help differentiate the case where two people are headed to the same goal, but unaware of each other (imagine both heading toward the same subway stop, both looking generally toward the destination) vs. real chasing, where the predator's gaze does not deviate from the prey's, and prey casts frantic periodic glances backward. (Since shapes in Heider & Simmel diagrams don't have gazes as such, a comparable metric might be the vector of forward movement.)

With a little care one might formulate a set of representations that, when taken in aggregate, could tell the story of 'chasing,' or at least, of one kind of chasing, where the `signatures' of chasing could be diagnosed by a trained objective party much as MRI results are interpreted by radiologists ('this discoloration indicates the presence of a tumor'). But there would be one crucial difference: in the `chasing' example our radiologist would be looking at traces of higher-order features, and therefore would have no idea if the traces under examination told the story of a cat chasing a squirrel, or Mario chasing Luigi, or even (if the features were constructed appropriately) whether Google was chasing Apple's market capitalization. A wide variety of phenomena could have comparable 'chasing' signatures. Classifying based on the signatures, and not direct recordings of the entities themselves, is the essence of abstraction.

Similar ideas have been instantiated in other fields. Kerr & Cohen (2010) built a system to infer the actions underlying the behavior of softbots in a virtual game environment, and discussed extensions to that system that would allow it to extract the intentional states of their human players. Blythe and colleagues (1999) developed an algorithm that used traces like the ones described above to interpret Heider & Simmel-style videogame interactions produced by human players; the algorithm was able to detect pursuit, evasion, fighting, courting, being courted, and to classify them better than could objective human raters. Another system designed by Crick and Scassellati (2010) used measurements from cameras attached to remote-controlled trucks to not only intuit the roles manifested by the other trucks controlled by human players, but even infer the rules to the game they were playing, and participate in it.

What is common to all these accounts is that, much as concepts like 'house' or 'dog' that are dominated by visual features (Gainotti 2011) can be represented, at least in part, as conjunctions of visual features of increasing complexity (Ullman et al. 2002), concepts like 'chase' that are idiomatically abstract, inherently social, and that define roles that must be filled by their constituent elements, can also be characterized, at least in part, by a conjunction of features — the key is that the system must have access to the appropriate features, and that some of the features likely do not arise directly out of SM components as we normally think of them — for instance, Crutch et al. (2013) proposed a set of abstract conceptual features, later extended by Troche et al. (2014) to include *Sensation; Action; Thought; Emotion; Social Interaction; Time; Space; Quantity; Polarity; Morality; Ease of Modifying; and Ease of Teaching*.

A richer set of features can allow abstract concepts to be more reasonably treated as feature bundles, but such a formulation leaves a great deal under-specified. For instance, unlike the visual features we normally consider when discussing semantics (a canonical apple always has whatever color it has), many abstract features are not static — they are traces across space and time, and the types which they collectively describe are not inherent in the tokens of the world (Barsalou 1999): as in a game of tag, during some periods you may be chasing; in other periods not. These feature dynamics are familiar elements in theoretical representations such as the simulators in Barsalou's Perceptual Symbol Systems theory (1999; 2003a, b) and Pulvermüller's Action-Perception Circuits (Pulvermüller 2013; Pulvermüller & Fadiga 2010). The research into how these things might be instantiated neurally is still very young.

Even so, the important thing for our purposes is not to nail down the details of a framework for representing abstract concepts, but rather to see how a construction built from abstract features is consistent with existing empirical and theoretical accounts of how collections of low-order features come to be aggregated together into higher-level constructs that achieve invariance with respect to unimportant parameters (Booth & Rolls 1998; Elliffe et al. 2002). We can see that what might be construed as a 'role' to be filled in a schema (Mandler 2004), or script (Schank & Abelson 1977), or frame (Minsky 1975) can be practically decomposed into a sub-region in feature space traced out by a series of detectors built up from SM primitives (the role of 'predator' has *this* set of features; the role of 'prey' has *that* set of features) and that an entity that exists at a certain location in feature-space is filling the role of predator, regardless of its nature (human; cartoon cat; stock price) and regardless of whatever other roles it might have been filling previously, or is concurrently filling in the moment.

Most importantly, we can see that this is exactly the process separately set forth to describe disparate aspects of the semantic system. Just as cascades of convergence/divergence zones are thought to aggregate collections of features across modalities (Barsalou 1999; Damasio 1989; Meyer & Damasio 2009), possibly spatially co-located in relation to the neural distance between the aggregated features (Simmons & Barsalou 2003) or restricted to a single CDZ that forms a common conceptual core for concrete concepts (Patterson 2007; Rogers et al. 2004; Rogers & McClelland 2004; Ueno et al. 2011) the outputs from these feature detectors converge in regions of heteromodal cortex to represent conceptual units defined by structures, roles, and relations.

Owing to the complexity inherent in the representations of abstract concepts, the neural real estate required to encode the semantic location in the representational feature space could be of similar or greater magnitude than that required to distinguish between concrete concepts like `kingfisher' vs. `bird' (Rogers et al. 2006), a distinction which could be made using only feature bundles arising from color and shape percepts local to visual processing areas. And because the concepts are abstract, we would predict that a conjunction of their features would be represented more rostrally than a conjunction of visual features, or features from any SM modalities, according to theories that posit a caudal to rostral abstraction gradient (Barsalou & Simmons 2003; Damasio 1989; Damasio et al. 2004; Meyer & Damasio 2009). The seeming conflict between the `abstraction gradient' (in which concepts become more distant from any particular SM representation) and the `specificity gradient' posited by unique entity accounts or semantic hub theories (Rogers et al. 2004, 2006; Tranel 2009) would be explained by loosening the definition of what, exactly, is being specifically represented, as described earlier: it's not only the ontological level of the stimulus (bird vs. Kingfisher) that determines specificity, but the precision required by the task to localize the concept in high-dimensional semantic space.

Viewed through the lens of this abstraction, the abstract words in our triads task, the sentences in our sentence localizer, social information generally, and both Brad Pitt and the Eiffel Tower share deep representational commonalities. These commonalities result in comparable activation in Royal Road regions of the temporal lobe. But why should this be?

Retrieving abstract components

With regard to the auditory and phonological requirements of conceptual processing, it's possible that these superior-temporal (ST) regions usually considered to support phonological and auditory processing are performing roles complementary to their original auditory functions.

For instance, since concrete words have direct SM representations in the world, when processing concrete words ST regions need only perform the phonological tasks required to decode words and access their meanings, a process that can occur relatively quickly due to the concrete advantage conferred by (among other things) increased SM representation in the feature catalogues.

Abstract words, on the other hand, lack these direct SM components. The greater ST involvement could therefore reflect co-activation of abstract words with other, related words whose contextual relationships support a kind of conceptual bootstrapping: since a *BOSS* is only meaningful in relation to some *SUBORDINATES* within an *ORGANIZATION*, increased STG activity may reflect mutual co-activation as the relational meaning of these word networks are unpacked over time. Activity in ST phonological regions would therefore support these extended retrieval demands (Binder et al. 2011, 2005). This mutual co-activation would be present in any task that used abstract words, which would explain the region's consistent appearance in meta-analyses. Retrieval of the appropriate semantic components would form a tightly-coupled system with semantic control processes, which proceed from posterior AG/MTG regions to Broca's area and other inferior-frontal regions (Davey et al. 2015; Noonan et al. 2013; Whitney et al. 2011a, 2011b).

Difficulty

On the surface, semantic control would seem to share much in common with our idiomatic notions of difficulty: semantic tasks that require a high level of control would also seem to be difficult tasks.

As we mentioned in the overall methods section, we controlled for difficulty in the GLM by amplitude-modulating (AM) all condition parameters with per-event and per-subject reaction time values. Assuming the variation in per-condition reaction time provides enough leverage to allow accurate parameter estimation, including this AM parameter in our model of each condition allows us to capture voxels that only activate when a trial is sufficiently difficult (thus increasing parameter sensitivity) as well as siphoning off the portion of difficulty-specific activation that occurs in a voxel that is also activated in a condition-general fashion (thus increasing parameter specificity).

This means that activations reported for triads contrasts should represent general activation for the triads task, with difficulty effects removed. This makes it easier to compare conditions that differ in difficulty, as many of our conditions do. But it also introduces a bias: instead of thinking that performing the triads task using CNM and NOV stimuli reflects the same process at two distinct difficulty levels, one could interpret `difficulty' as the presence of operations in one condition that are absent in the other. In other words, instead of a nuisance variable to be controlled, perhaps difficulty is a crucial and distinguishing factor in different flavors of semantic processing. This is a similar attitude to that expressed by Skipper and Olson (2014) with regard to controlling semantic features: you can equate two different-seeming semantic classes (abstract and concrete, in their case) on a variety of features, but in doing so you might wind up with strange stimuli that do not reflect the semantic classes you initially set out to investigate.

Considering the differences between the triads stimuli, it's worth asking what is the role of difficulty in all this? And does the response to difficulty tell us anything about semantic function?

Difficulty methods: Image analysis

We preprocessed the data according to the general methods for the triads task, described earlier.

For the input to our per-subject/session GLM, we first computed the median reaction time (RT) for each semantic condition (CNM, COM, HSS, LSS, NOV). Using RT as a proxy for difficulty, we then split each of these conditions into low- and high-difficulty sub-conditions (e.g., CNM_LOW, CNM_HIGH, etc.) and used these sub-conditions in our GLM in place of the original conditions. To give a fuller representation of the BOLD response to semantic features, the nuisance regressors for valence and arousal were not included. In all other respects the GLM was as described in the general methods.

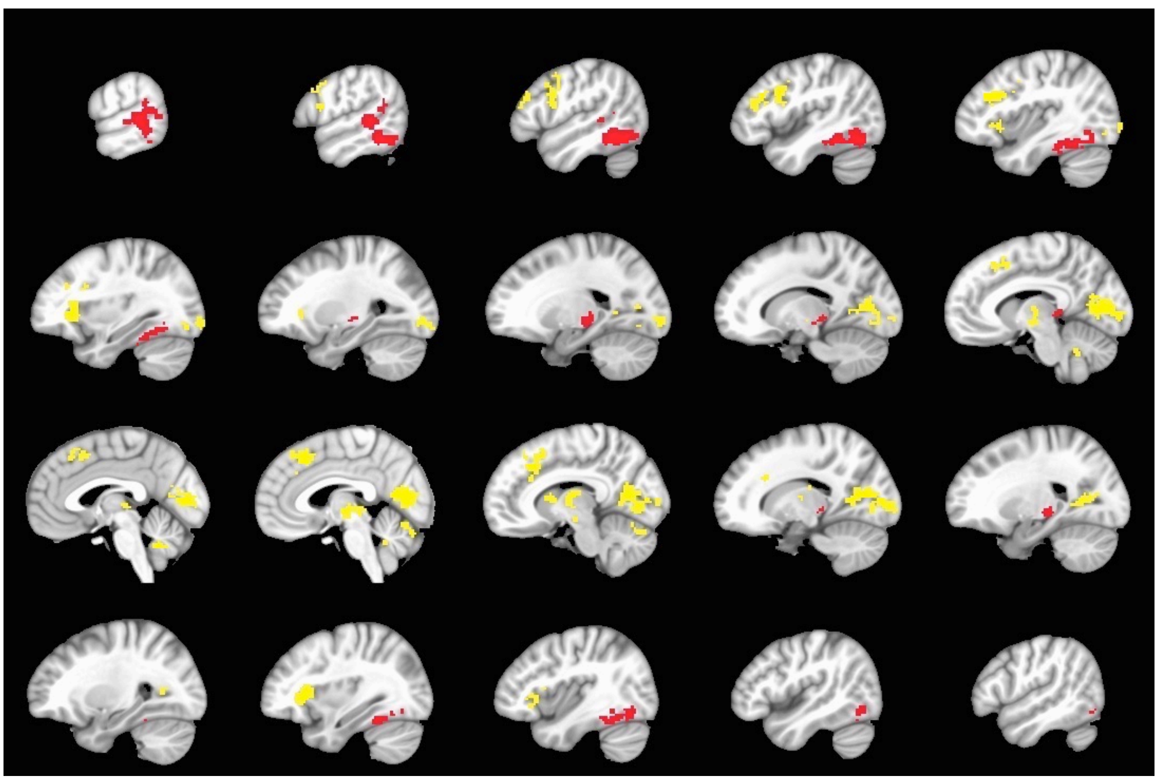
Group analysis proceeded as described in the general methods; the principal contrast of interest was between high- and low-difficulty conditions (CNM_HIGH + … + NOV_HIGH - CNM_LOW - … - NOV_LOW). To see whether the difficulty effects varied between abstract and concrete semantic processing, we also created an ABS_DIFF vs. CONC_DIFF contrast, which compared the difficulty owing to abstract processing

(HSS_HIGH - HSS_LOW + LSS_HIGH - LSS_LOW) with the difficulty owing to concrete processing (CNM_HIGH - CNM_LOW + COM_HIGH - COM_LOW). For reference, we also computed the results for general, non-semantic difficulty by performing group analysis on the reaction time nuisance parameter for the NUM condition. To examine the relationship between semantic difficulty and RR activation, we also computed the conjunction of the group activation maps for semantic difficulty, and the conjunction map for the (SENT>JABBER and NOV>NUM) contrasts, described earlier in this section.

Difficulty results

The following image shows the combined semantic (red) and non-semantic (yellow) difficulties. The semantic difficulty (red) is restricted to our usual TL ROI; for reference (as a sanity check, because it barely activates the TL) the non-semantic difficulty includes activations from our entire acquisition volume.

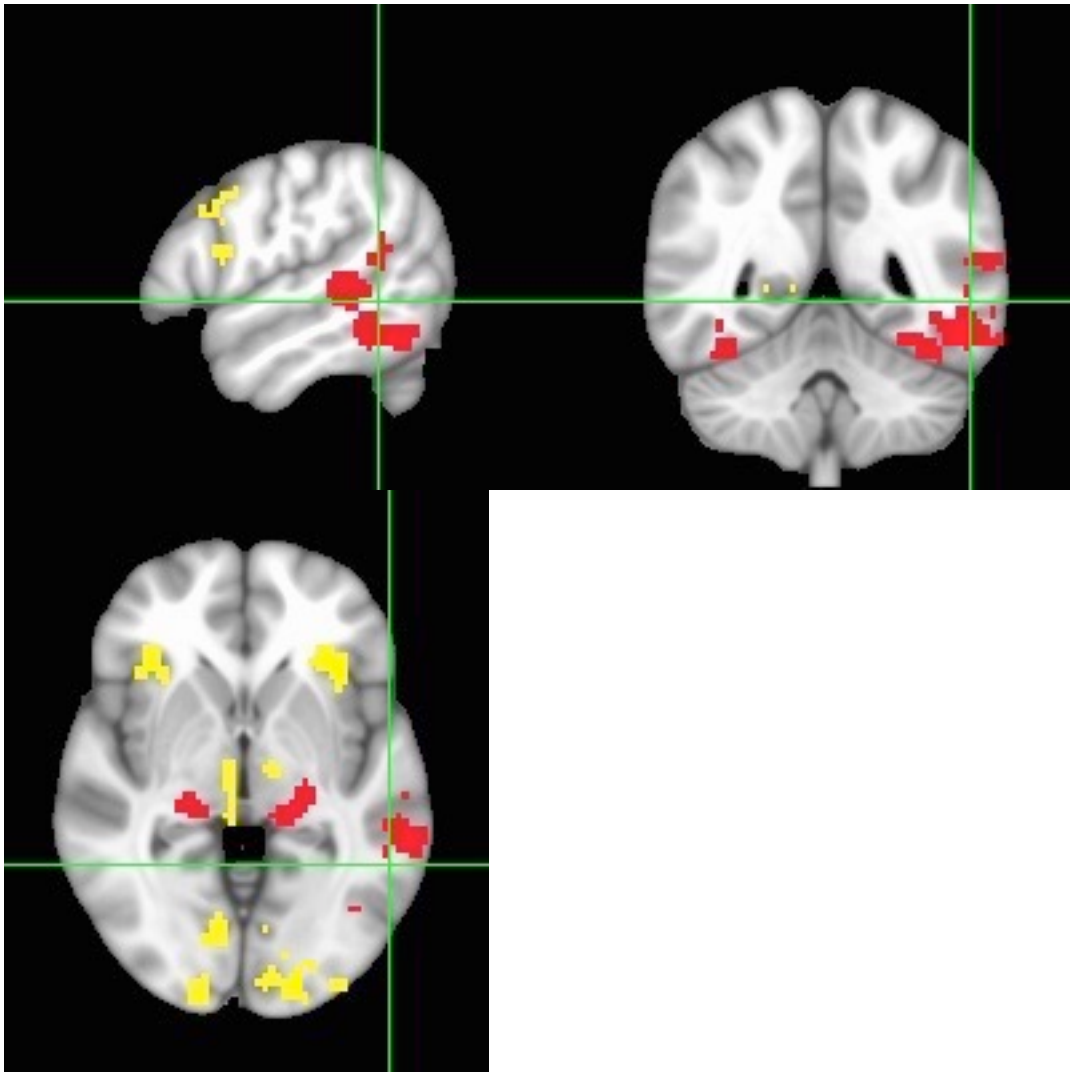
Figure 35. Semantic (red) and non-semantic (yellow) difficulty activations, LH to RH.



Semantic and non-semantic difficulty do not overlap, at all, in the TL. We can interpret this to mean that what stresses the system during difficult (measured by RT) semantic processing is additional to the attentional and working memory demands mediated outside of the TL. It's especially noteworthy that neither type of difficulty affects the ATL, suggesting that the extensive activation we find there in response to sentence and triads processing is unpolluted by difficulty confounds, either in terms of general cognitive support (e.g., attentional and working memory resources) required for difficult tasks, or of cognitive activity that underlies semantics in particular.

Our ABS_DIFF vs. CONC_DIFF contrast produced no significant activations, suggesting that semantic difficulty for abstract triads does not differ from semantic difficulty for concrete triads. This is surprising, since the RR profile appears exclusively when processing triads that contain abstract words. This raises the question as to the relationship between difficulty and semantic control. The following figure shows semantic and non-semantic difficulty maps with the crosshairs at (-54, -49, -2 LPI, MNI), the location associated with maximal semantic control according to a recent meta-analysis (Noonan et al. 2013), and verified by rTMS (Krieger-Redwood & Jefferies, 2014).

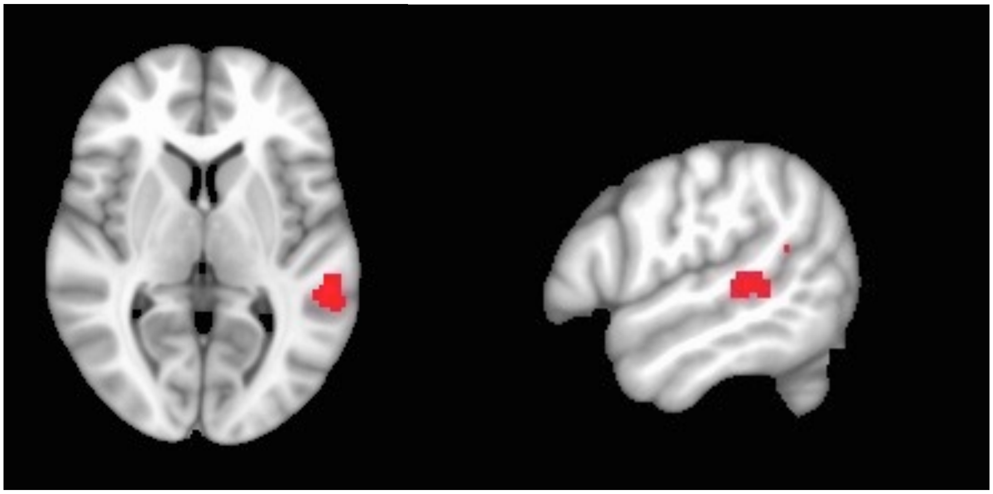
Figure 36. Semantic difficulty activations (in red) surround the location associated with maximal semantic control activity (-54, -49, -2 LPI, MNI) according to Noonan et al. (2013).



The activation results don't intersect the specified semantic control ROI, but semantic difficulty activation closely fences it in on three sides, suggesting that difficulty in semantic processing might be closely related to issues of semantic control across all types of semantic content.

The following figure shows the conjunction between semantic difficulty and RR.

Figure 37. Common activation between semantic difficulty and Royal Road conjunction activation.



These results suggest that perhaps there is common ground between semantic control, semantic difficulty, and the kinds of semantic tasks that drive posterior RR activation, although including the RT nuisance regressors for the analyses reported in the main body of this document appears to have been effective in isolating general semantics effects from difficulty-specific effects, with only the region in the figure above included in both the general- and difficulty-specific analyses.

All together, it would seem that the posterior portion of the RR plays a nuanced role that involves multiple aspects of semantic processing in support of the decision required by the triads task, especially when the processing requires selection and integration of components that require larger contextual buttressing, as is the case with abstract triads or full sentences.

Difficulty as broad-spectrum processing

Some theorists (e.g. Duncan 2013) believe that general cognitive processes occur as a result of re-purposing the same neural circuits to subserve diverse tasks. According to this position, the same neurons change their response profiles to select for what is relevant at the moment (Duncan 2001). For instance, the same cells that code for stimulus identity when identity is relevant, change their tunings to stimulus location when location replaces identity as the actionable task feature (Rao et al. 1997). Viewing the brain in light of this sort of multiple-demand operation would appear to conflict with analyses, such as ours, that purport to explain certain anatomical regions in terms of a more specialized functional repertoire (Kanwisher 2010), rather than in terms of a broad and generalized computational catalogue that changes in accordance with the task at hand.

Fortunately, the results we present here, focused on the temporal lobes in general and the ATL in particular, would seem not to be invalidated by MD findings, which highlight (principally) the contribution of frontal and parietal regions to broad-spectrum cognition. In particular, difficulty contrasts involving the putative MD system do not involve the temporal regions we have identified as principally semantic (Duncan 2013; Fedorenko et al. 2012). This is an especially strong piece of confirmatory evidence owing to the difficulties in separating activation due to semantic processing from activation due to auxiliary processing that supports semantic activity, but is not in itself semantically related. While we have attempted to control for this possibility, perfect control is difficult to achieve in a complex domain, and achieving it can be at the expense of the very experimental condition you set out to investigate (Skipper & Olson, 2014).

With this caveat in hand, the results from Duncan (2013) and Fedorenko and colleagues (2012) are especially important. Their investigations, which manipulated difficulty across a diverse range of tasks, provide strong corroborating evidence to our conclusion that neither explicit semantic difficulty, nor more general task difficulty, drives activation in the temporal regions we have extensively discussed in this paper. Despite the complexity and fundamental nature of semantic processing, the results we've shown in these temporal regions appear relatively un-polluted with non-semantic concerns.

Interpreting semantic dementia results in light of this hypothesis

Superior temporal gyrus and semantic dementia

Results from semantic dementia (SD) support this role for STG, indirectly. If we believe the RR plays a role in general semantic integration, then we would expect to find the RR spared in brain-damaged patients who can perform integrative tasks like sentence comprehension. This seems to be the case in SD patients, who are characterized by their relatively intact cognitive functioning aside from deficits in word comprehension. Patient performance on simple sentences is often comparable to controls (Hodges & Patterson, 1995).

SD etiology generally finds large regions in STG preserved (Mummery et al. 2000), including Wernicke's area, and sometimes even superior aspect of TP (Rosen et al. 2002). Since TP has been shown to retain some modal-specificity in its superior and inferior aspects (Skipper et al. 2011; Ding et al. 2009) it's possible that sentences (spoken and written) could still have access to integrative processing in STG itself, or in another region to which it is connected. When STG is not preserved, performance drops. Results from Ash and colleagues (2009) show that verbal fluency in SD correlates with STG damage. This suggests that when the RR is compromised, one aspect of the functionality we've imputed to it — the ability to assemble composite meanings from individual pieces — decays.

Additionally, all integration needn't exclusively occur in anterior aspects of TL. A meta-analysis on the components of syntactic and semantic integration in sentence processing (Hagoort 2014) reports many results showing that that these types of integration takes place posterior to the ATL in superior and middle regions of the Royal Road, which will be better preserved or even uncompromised in SD, depending on the state of the disease. Whatever the natural responsibilities of different STG regions, it's possible that comparable but non-dominant locations may activate in compensatory fashion in the face of damage.

Temporal pole and semantic dementia

While STG might be relatively well preserved in SD, our conjunction results also implicate the middle convolution of temporal pole. The involvement of this region in semantic integration would make a great deal of sense, as it exists at the anterior culmination of both abstraction gradients (Damasio 1989; Visser et al. 2012), and is implicated in studies of both social processing and unique entity processing (e.g., Tranel 2009).

Results from the unique entity literature are especially interesting in light of this integration argument. We might consider the ability to identify and name a particular entity such as the Eiffel Tower, or Brad Pitt, as the process of drawing an irregular boundary through a very high-dimensional space of shared features, and associating that very particular distribution of features with a name, which is itself an irregular boundary in phonological space. Bundling together these features is itself an integration process. Such an account is consistent with the aphasia that results from TP damage due to epilepsy or surgical resection, although the hemi-specific anomic pathologies are suggestive of a deeper organizational structure than has been presented here, in which unilateral damage results in inability to integrate semantic knowledge with a name (LH damage) or SM information with concept identity (RH damage) (Drane at al. 2014; Waldron et al. 2014).

The case for TP's role in semantic processing is strong; but its location in the atrophic SD `danger zone' makes its inclusion as a semantic integrator troublesome. One would expect damage to an area subserving such a fundamental integrative process to produce difficulties comparable in magnitude to the single-word comprehension deficits demonstrated by SD patients, and yet such is not the case, as described earlier.

A mitigating factor is that grey matter damage in SD is more severe in inferior and more caudal regions, with the site of maximal atrophy recently suggested in two studies to be in anterior aspects of FG and PHG, based on both imaging and behavioral data (Binney et al. 2010; Mion et al. 2010). It is therefore possible that the disease spares enough tissue in TP to preserve basic functioning, so that patients appear little compromised on the batteries involving syntactic and grammatical fluency (e.g., Grossman et al. 2005). This seems plausible considering the brain's ability to compensate for regional damage by recruiting from symmetric contralateral structures. In other words, polar MTG is probably less compromised than other structures, but even when it is compromised, it's possible that the equivalent region in the other hemisphere can pick up the slack.

It's also important to remember that tests assaying syntactic and sentence-processing abilities may reveal less than they appear to reveal on this topic, as they use only "simple, high frequency words" (Hodges et al. 1995). It's possible that more rigorous testing of SD patients' sentence-comprehension or integrative capacity would uncover greater performance variations than are currently considered typical of the condition.

Summary

Our results show that ATL and TP — and indeed, a larger region running along STS that we've called the Royal Road — are clearly involved with general semantic processing; evidence for the involvement of these same regions in social and emotional processing is compelling in other literature, but not supported by the present results, suggesting that semantic cognition in general, and TL involvement with emotional and social stimuli in particular, is neither automatic nor task-independent, but rather unfolds as necessary to support task demands. The tailoring of the semantic response to the task and stimuli, combined with the under-specification of many aspects of both the stimuli and the tasks used to assay semantic cognition, account for the many inconsistencies in the literature.

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Appendix: stimuli

Triads stimuli single-run example

SAMPLE	TGT1	TGT2	CLASS	CORR
gurgling	swishing	droning	COM	1
era	age	project	LSS	1
ten	eight	forty-three	NUM	1
cheetah	pelican	tiger	CNM	2
seventy	seventy-six	sixty-one	NUM	1
mystery	pleasure	puzzle	LSS	2
pride	dignity	area	HSS	1
[NULL]	X	X	X	1
game	contest	gravity	LSS	1
sixty-eight	twenty	eighty-two	NUM	2
yellow	orange	purple	COM	1
xxxxxxxxxxxxx	xxx	xxxxxxxxxxxxxx	XLT	2
[NULL]	X	X	X	1
seventy-six	eighty-eight	thirty	NUM	1
oath	promise	secret	HSS	1
[NULL]	X	X	X	1
private	single	personal	LSS	2
jealousy	legend	envy	HSS	2
tribe	crowd	family	HSS	2
news	media	prayer	HSS	1
eighty-one	forty-nine	eighty-five	NUM	2
silent	muffled	shrill	COM	1
media	order	dark	NOV	1
jingle	tune	mood	LSS	1
ghost	goldfish	speech	NOV	1
legend	plan	toad	NOV	1
pink	green	red	COM	2
talking	ringing	speaking	COM	2
fable	giraffe	fate	NOV	1
xxxxxxxxxx	xxx	xxxxxxxxxxxx	XLT	2
fate	destiny	future	LSS	1
sheep	hen	pig	CNM	2
[NULL]	X	X	X	1
religion	custom	faith	HSS	2
job	career	crime	HSS	1
xxxxxxxxxxxxx	xx	xxxxxxxxxxxxxxx	XLT	2

jaguar	panther	snail	CNM	1
loud	shot	humming	COM	1
booming	hissing	rumbling	COM	2
thirty	sixty-six	twenty-two	NUM	2
[NULL]	X	X	X	1
xxxxx	xxx	xxxxxxxxxxxxx	XLT	1
quiet	ticking	thunder	COM	1
[NULL]	X	X	X	1
xxxxx	xxx	xxxxxxxxxxxxxxxx	XLT	1
xxxxxxxx	xxxxxxx	xxxxxxxxxxxx	XLT	1
seven	ten	two	NUM	1
ethics	morality	honesty	HSS	1
[NULL]	X	X	X	1
turkey	duck	owl	CNM	1
[NULL]	X	X	X	1
spider	ant	buffalo	CNM	1
goose	lamb	swan	CNM	2
spirit	vote	ghost	LSS	2
[NULL]	X	X	X	1
hamster	buffalo	mouse	CNM	2
promise	eagle	delight	NOV	1
gossip	camel	logic	NOV	1
[NULL]	X	X	X	1
horse	wit	vulture	NOV	1
gravity	dot	bull	NOV	1
eel	worm	snake	CNM	2
xxxxxxxxxxxxxxx	xx	xxxxxxxxxxxxxxxx	XLT	2
magic	curse	trick	LSS	2
[NULL]	X	X	X	1
hope	rage	wish	HSS	2
ant	baboon	beetle	CNM	2
grief	guilt	sadness	HSS	2
courage	bravery	vanity	HSS	1
brown	bronze	transparent	COM	1
humming	howl	buzzing	COM	2
[NULL]	X	X	X	1
xxxxxxxxxx	xx	xxxxxxxxxxxxx	XLT	2
seventy-nine	thirty-eight	eighty-seven	NUM	2
xxxxxxxxxxxxxx	xxxx	xxxxxxxxxxxxxxx	XLT	2
raisin	peanut	cherry	CNM	2
origin	source	relief	LSS	1

[NULL]	X	X	X	1
fashion	desire	music	NOV	1
eighty	seventy-four	eighty-one	NUM	2
regret	logic	sorrow	HSS	2
sixty-seven	thirty-three	seventy-one	NUM	2
honk	reality	nation	NOV	1
xxxxxxxxxxxxxxx	xxxxxxxx	xxxxxxxxxxxxxxxx	XLT	2
xxxxx	xxxx	xxxxxxxxxxxxxxxx	XLT	1
maroon	burgundy	gray	COM	1
thirty-three	thirty-two	thirty-seven	NUM	1
[NULL]	X	X	X	1
support	proof	hen	NOV	1
danger	injury	threat	LSS	2
xxx	xx	xxxxxxxxxx	XLT	1
[NULL]	X	X	X	1
seventy-one	eighty-seven	twenty-four	NUM	1
gnat	walrus	fly	CNM	2
[NULL]	X	X	X	1
result	party	outcome	LSS	2
empire	chicken	hunger	NOV	1
camel	pony	sheep	CNM	1
cone	cylinder	cross	COM	1
stamina	energy	survival	LSS	1

Sentence localizer stimuli run 1 (day 1)

Word	Item_No.	Condition	Block
THE	1	Sentence	Block_1
DOG	1	Sentence	Block_1
CHASED	1	Sentence	Block_1
THE	1	Sentence	Block_1
CAT	1	Sentence	Block_1
ALL	1	Sentence	Block_1
DAY	1	Sentence	Block_1
LONG	1	Sentence	Block_1
JILL	2	Sentence	Block_1
LIKES	2	Sentence	Block_1
TO	2	Sentence	Block_1
WEAR	2	Sentence	Block_1
HATS	2	Sentence	Block_1
OF	2	Sentence	Block_1
ALL	2	Sentence	Block_1

KINDS	2	Sentence	Block_1
RON	3	Sentence	Block_1
PLAYED	3	Sentence	Block_1
A	3	Sentence	Block_1
GAME	3	Sentence	Block_1
WITH	3	Sentence	Block_1
HIS	3	Sentence	Block_1
LITTLE	3	Sentence	Block_1
BROTHER	3	Sentence	Block_1
ANN	4	Sentence	Block_1
BAKED	4	Sentence	Block_1
A	4	Sentence	Block_1
CAKE	4	Sentence	Block_1
FOR	4	Sentence	Block_1
HER	4	Sentence	Block_1
MOM'S	4	Sentence	Block_1
BIRTHDAY	4	Sentence	Block_1
MIKE	5	Sentence	Block_1
AND	5	Sentence	Block_1
LARRY	5	Sentence	Block_1
HAVE	5	Sentence	Block_1
ALWAYS	5	Sentence	Block_1
BEEN	5	Sentence	Block_1
GOOD	5	Sentence	Block_1
FRIENDS	5	Sentence	Block_1
INCORMED	1	Nonword	Block_2
RALMING	1	Nonword	Block_2
CRE	1	Nonword	Block_2
EMTO	1	Nonword	Block_2
SMASP	1	Nonword	Block_2
OMOULT	1	Nonword	Block_2
MINTER	1	Nonword	Block_2
TEWLAIRE	1	Nonword	Block_2
URDED	2	Nonword	Block_2
CRE	2	Nonword	Block_2
PLAZZ	2	Nonword	Block_2
HAGEED	2	Nonword	Block_2
KOUR	2	Nonword	Block_2
VELIC	2	Nonword	Block_2
GHUG'S	2	Nonword	Block_2
NIS	2	Nonword	Block_2

FUCH	3	Nonword	Block_2
CRE	3	Nonword	Block_2
GEVE	3	Nonword	Block_2
WENINE	3	Nonword	Block_2
THRAGED	3	Nonword	Block_2
TEEP	3	Nonword	Block_2
EMES	3	Nonword	Block_2
OLEMED	3	Nonword	Block_2
DATHER'S	4	Nonword	Block_2
CRE	4	Nonword	Block_2
MELOYSE	4	Nonword	Block_2
NER	4	Nonword	Block_2
UCONG	4	Nonword	Block_2
MITH	4	Nonword	Block_2
CRE	4	Nonword	Block_2
KRELLA	4	Nonword	Block_2
KIEVE	5	Nonword	Block_2
QUIFECT	5	Nonword	Block_2
VOOP	5	Nonword	Block_2
OBIST	5	Nonword	Block_2
OLP	5	Nonword	Block_2
BUKE	5	Nonword	Block_2
FO	5	Nonword	Block_2
E	5	Nonword	Block_2
NICIA	6	Nonword	Block_3
CRE	6	Nonword	Block_3
LAS	6	Nonword	Block_3
UF	6	Nonword	Block_3
BROR	6	Nonword	Block_3
SKEK	6	Nonword	Block_3
LAS	6	Nonword	Block_3
NIS	6	Nonword	Block_3
STULPIRT'S	7	Nonword	Block_3
NIS	7	Nonword	Block_3
ZOOT	7	Nonword	Block_3
NIS	7	Nonword	Block_3
YEI	7	Nonword	Block_3
CRE	7	Nonword	Block_3
EMTO	7	Nonword	Block_3
NER	7	Nonword	Block_3
CLISY	8	Nonword	Block_3

NIS	8	Nonword	Block_3
YULPED	8	Nonword	Block_3
SENNIL	8	Nonword	Block_3
STUTIONS	8	Nonword	Block_3
CLIB	8	Nonword	Block_3
PHLOOSHER	8	Nonword	Block_3
LAS	8	Nonword	Block_3
IM	9	Nonword	Block_3
CRE	9	Nonword	Block_3
IM	9	Nonword	Block_3
BEVS	9	Nonword	Block_3
CRE	9	Nonword	Block_3
BAIMS	9	Nonword	Block_3
STALED	9	Nonword	Block_3
CRE	9	Nonword	Block_3
ANK	10	Nonword	Block_3
TWOU	10	Nonword	Block_3
FASP	10	Nonword	Block_3
CRE	10	Nonword	Block_3
DOOVE	10	Nonword	Block_3
NER	10	Nonword	Block_3
GOR	10	Nonword	Block_3
EN	10	Nonword	Block_3
LIZ	6	Sentence	Block_4
REALLY	6	Sentence	Block_4
WANTED	6	Sentence	Block_4
TO	6	Sentence	Block_4
GET	6	Sentence	Block_4
A	6	Sentence	Block_4
LITTLE	6	Sentence	Block_4
PUPPY	6	Sentence	Block_4
STEVE	7	Sentence	Block_4
WAS	7	Sentence	Block_4
LATE	7	Sentence	Block_4
TO	7	Sentence	Block_4
SCHOOL	7	Sentence	Block_4
BECAUSE	7	Sentence	Block_4
HE	7	Sentence	Block_4
OVERSLEPT	7	Sentence	Block_4
WHEN	8	Sentence	Block_4
JOHN	8	Sentence	Block_4

CAME	8	Sentence	Block_4
HOME	8	Sentence	Block_4
HIS	8	Sentence	Block_4
DAD	8	Sentence	Block_4
WAS	8	Sentence	Block_4
THERE	8	Sentence	Block_4
ALEX	9	Sentence	Block_4
WAS	9	Sentence	Block_4
TIRED	9	Sentence	Block_4
SO	9	Sentence	Block_4
HE	9	Sentence	Block_4
TOOK	9	Sentence	Block_4
A	9	Sentence	Block_4
NAP	9	Sentence	Block_4
BETH	10	Sentence	Block_4
WALKED	10	Sentence	Block_4
HER	10	Sentence	Block_4
DOG	10	Sentence	Block_4
IN	10	Sentence	Block_4
THE	10	Sentence	Block_4
PARK	10	Sentence	Block_4
NEARBY	10	Sentence	Block_4
THE	11	Sentence	Block_5
SQUIRREL	11	Sentence	Block_5
MADE	11	Sentence	Block_5
A	11	Sentence	Block_5
NEST	11	Sentence	Block_5
ON	11	Sentence	Block_5
THE	11	Sentence	Block_5
TREE	11	Sentence	Block_5
THE	12	Sentence	Block_5
BIRDS	12	Sentence	Block_5
SANG	12	Sentence	Block_5
OUTSIDE	12	Sentence	Block_5
THE	12	Sentence	Block_5
WINDOW	12	Sentence	Block_5
ALL	12	Sentence	Block_5
MORNING	12	Sentence	Block_5
THE	13	Sentence	Block_5
BEE	13	Sentence	Block_5
WAS	13	Sentence	Block_5

FLYING	13	Sentence	Block_5
IN	13	Sentence	Block_5
THE	13	Sentence	Block_5
FLOWER	13	Sentence	Block_5
FIELD	13	Sentence	Block_5
GRANDMA	14	Sentence	Block_5
MADE	14	Sentence	Block_5
SOME	14	Sentence	Block_5
COOKIES	14	Sentence	Block_5
FOR	14	Sentence	Block_5
HER	14	Sentence	Block_5
LITTLE	14	Sentence	Block_5
TIMMY	14	Sentence	Block_5
THE	15	Sentence	Block_5
BEAR	15	Sentence	Block_5
CAUGHT	15	Sentence	Block_5
SOME	15	Sentence	Block_5
FISH	15	Sentence	Block_5
IN	15	Sentence	Block_5
THE	15	Sentence	Block_5
STREAM	15	Sentence	Block_5
ZOOK	11	Nonword	Block_6
U	11	Nonword	Block_6
STENANT	11	Nonword	Block_6
CRE	11	Nonword	Block_6
NARGE	11	Nonword	Block_6
GHIRING	11	Nonword	Block_6
CRE	11	Nonword	Block_6
PLAIRE	11	Nonword	Block_6
BOKER	12	Nonword	Block_6
DESH	12	Nonword	Block_6
FE	12	Nonword	Block_6
CRE	12	Nonword	Block_6
DRILES	12	Nonword	Block_6
LER	12	Nonword	Block_6
CICE	12	Nonword	Block_6
FRISTY'S	12	Nonword	Block_6
PHREZ	13	Nonword	Block_6
CRE	13	Nonword	Block_6
EKED	13	Nonword	Block_6
PICUSE	13	Nonword	Block_6

EMTO	13	Nonword	Block_6
PECH	13	Nonword	Block_6
CRE	13	Nonword	Block_6
ZEIGELY	13	Nonword	Block_6
U	14	Nonword	Block_6
FULTER	14	Nonword	Block_6
SWEIK	14	Nonword	Block_6
U	14	Nonword	Block_6
OLP	14	Nonword	Block_6
IM	14	Nonword	Block_6
YUTHED	14	Nonword	Block_6
IM	14	Nonword	Block_6
JERN	15	Nonword	Block_6
SWOAMED	15	Nonword	Block_6
IPTOR	15	Nonword	Block_6
CHURNT	15	Nonword	Block_6
SEPOS	15	Nonword	Block_6
FE	15	Nonword	Block_6
UF	15	Nonword	Block_6
DWOZ	15	Nonword	Block_6
THE	16	Sentence	Block_7
CAT	16	Sentence	Block_7
WAS	16	Sentence	Block_7
WATCHING	16	Sentence	Block_7
THE	16	Sentence	Block_7
BIRD	16	Sentence	Block_7
FROM	16	Sentence	Block_7
AFAR	16	Sentence	Block_7
PHIL	17	Sentence	Block_7
SAW	17	Sentence	Block_7
WHERE	17	Sentence	Block_7
HIS	17	Sentence	Block_7
MOM	17	Sentence	Block_7
HID	17	Sentence	Block_7
THE	17	Sentence	Block_7
PRESENTS	17	Sentence	Block_7
LITTLE	18	Sentence	Block_7
JESSIE	18	Sentence	Block_7
DREAMT	18	Sentence	Block_7
OF	18	Sentence	Block_7
BEING	18	Sentence	Block_7

A	18	Sentence	Block_7
BALLET	18	Sentence	Block_7
DANCER	18	Sentence	Block_7
WHEN	19	Sentence	Block_7
THE	19	Sentence	Block_7
SUN	19	Sentence	Block_7
SET	19	Sentence	Block_7
IT	19	Sentence	Block_7
GOT	19	Sentence	Block_7
COLD	19	Sentence	Block_7
FAST	19	Sentence	Block_7
PETER	20	Sentence	Block_7
READ	20	Sentence	Block_7
A	20	Sentence	Block_7
GREAT	20	Sentence	Block_7
BOOK	20	Sentence	Block_7
ABOUT	20	Sentence	Block_7
ORCA	20	Sentence	Block_7
WHALES	20	Sentence	Block_7
JENNY	21	Sentence	Block_8
DROVE	21	Sentence	Block_8
THE	21	Sentence	Block_8
CAR	21	Sentence	Block_8
TO	21	Sentence	Block_8
SCHOOL	21	Sentence	Block_8
LAST	21	Sentence	Block_8
WEEK	21	Sentence	Block_8
THE	22	Sentence	Block_8
CHILD	22	Sentence	Block_8
BENT	22	Sentence	Block_8
DOWN	22	Sentence	Block_8
TO	22	Sentence	Block_8
SMELL	22	Sentence	Block_8
THE	22	Sentence	Block_8
ROSE	22	Sentence	Block_8
THE	23	Sentence	Block_8
BLUE	23	Sentence	Block_8
MITTENS	23	Sentence	Block_8
ARE	23	Sentence	Block_8
ON	23	Sentence	Block_8
THE	23	Sentence	Block_8

TOP	23	Sentence	Block_8
SHELF	23	Sentence	Block_8
JAMIE	24	Sentence	Block_8
USED	24	Sentence	Block_8
EGGS	24	Sentence	Block_8
FLOUR	24	Sentence	Block_8
AND	24	Sentence	Block_8
MILK	24	Sentence	Block_8
TO	24	Sentence	Block_8
BAKE	24	Sentence	Block_8
ALEX	25	Sentence	Block_8
WORE	25	Sentence	Block_8
A	25	Sentence	Block_8
WOOL	25	Sentence	Block_8
SWEATER	25	Sentence	Block_8
TO	25	Sentence	Block_8
KEEP	25	Sentence	Block_8
WARM	25	Sentence	Block_8
TIPAT	16	Nonword	Block_9
U	16	Nonword	Block_9
PRENDY	16	Nonword	Block_9
DRYM	16	Nonword	Block_9
UB	16	Nonword	Block_9
CRE	16	Nonword	Block_9
OLP	16	Nonword	Block_9
ZEICHING	16	Nonword	Block_9
FRAWING	17	Nonword	Block_9
SPRAD	17	Nonword	Block_9
NIS	17	Nonword	Block_9
DUT	17	Nonword	Block_9
UF	17	Nonword	Block_9
JUPY	17	Nonword	Block_9
SPUBED	17	Nonword	Block_9
THRUDDED	17	Nonword	Block_9
PIV	18	Nonword	Block_9
WUBA	18	Nonword	Block_9
WOS	18	Nonword	Block_9
PAFFING	18	Nonword	Block_9
DEBON	18	Nonword	Block_9
TRIENED	18	Nonword	Block_9
LE	18	Nonword	Block_9

KIF	18	Nonword	Block_9
CRE	19	Nonword	Block_9
FULP	19	Nonword	Block_9
CRE	19	Nonword	Block_9
DESTRY	19	Nonword	Block_9
VOUTH	19	Nonword	Block_9
KETEED	19	Nonword	Block_9
IM	19	Nonword	Block_9
CRE	19	Nonword	Block_9
VOOM	20	Nonword	Block_9
GOR	20	Nonword	Block_9
SWINT	20	Nonword	Block_9
CHALT	20	Nonword	Block_9
THWOLF	20	Nonword	Block_9
IM	20	Nonword	Block_9
BARSELY	20	Nonword	Block_9
PLEECE	20	Nonword	Block_9
SUVA	21	Nonword	Block_10
TRINMORD	21	Nonword	Block_10
IPTOR	21	Nonword	Block_10
FLES	21	Nonword	Block_10
RINEFOSE	21	Nonword	Block_10
ROGLY	21	Nonword	Block_10
MITH	21	Nonword	Block_10
CRE	21	Nonword	Block_10
SCIPE	22	Nonword	Block_10
MITH	22	Nonword	Block_10
KNULGE	22	Nonword	Block_10
NIS	22	Nonword	Block_10
OG	22	Nonword	Block_10
CLERF	22	Nonword	Block_10
SPOLTER	22	Nonword	Block_10
OLP	22	Nonword	Block_10
KOUR	23	Nonword	Block_10
TRUKE	23	Nonword	Block_10
CRE	23	Nonword	Block_10
THWOMP	23	Nonword	Block_10
SPELM	23	Nonword	Block_10
WEFFEN	23	Nonword	Block_10
JORR	23	Nonword	Block_10
THUCH	23	Nonword	Block_10

FO	24	Nonword	Block_10
OG	24	Nonword	Block_10
CRE	24	Nonword	Block_10
GLAMN	24	Nonword	Block_10
IR	24	Nonword	Block_10
VIRCH	24	Nonword	Block_10
YERFED	24	Nonword	Block_10
BIEFINGS	24	Nonword	Block_10
KE	25	Nonword	Block_10
HUINT	25	Nonword	Block_10
YIG	25	Nonword	Block_10
CRE	25	Nonword	Block_10
UF	25	Nonword	Block_10
IM	25	Nonword	Block_10
UL	25	Nonword	Block_10
USP	25	Nonword	Block_10
THE	26	Sentence	Block_11
BASEBALL	26	Sentence	Block_11
TEAM	26	Sentence	Block_11
IS	26	Sentence	Block_11
PLAYING	26	Sentence	Block_11
A	26	Sentence	Block_11
GAME	26	Sentence	Block_11
SOON	26	Sentence	Block_11
THE	27	Sentence	Block_11
NEW	27	Sentence	Block_11
PUPPY	27	Sentence	Block_11
BARKED	27	Sentence	Block_11
AND	27	Sentence	Block_11
WAGGED	27	Sentence	Block_11
HER	27	Sentence	Block_11
TAIL	27	Sentence	Block_11
MICHAEL	28	Sentence	Block_11
ENJOYS	28	Sentence	Block_11
WATCHING	28	Sentence	Block_11
THE	28	Sentence	Block_11
DUCKS	28	Sentence	Block_11
AT	28	Sentence	Block_11
THE	28	Sentence	Block_11
PARK	28	Sentence	Block_11
THE	29	Sentence	Block_11

BABY	29	Sentence	Block_11
SUCKED	29	Sentence	Block_11
ON	29	Sentence	Block_11
A	29	Sentence	Block_11
BOTTLE	29	Sentence	Block_11
OF	29	Sentence	Block_11
MILK	29	Sentence	Block_11
LUCAS	30	Sentence	Block_11
TOOK	30	Sentence	Block_11
OUT	30	Sentence	Block_11
THE	30	Sentence	Block_11
BROOM	30	Sentence	Block_11
AND	30	Sentence	Block_11
STARTED	30	Sentence	Block_11
SWEEPING	30	Sentence	Block_11
CRON	26	Nonword	Block_12
DACTOR	26	Nonword	Block_12
MIK	26	Nonword	Block_12
MAMP	26	Nonword	Block_12
FAMBED	26	Nonword	Block_12
BLALK	26	Nonword	Block_12
CRE	26	Nonword	Block_12
MALVITE	26	Nonword	Block_12
DAP	27	Nonword	Block_12
DRELLO	27	Nonword	Block_12
SMOP	27	Nonword	Block_12
UB	27	Nonword	Block_12
PLID	27	Nonword	Block_12
KAV	27	Nonword	Block_12
CRE	27	Nonword	Block_12
REPLODE	27	Nonword	Block_12
CAL	28	Nonword	Block_12
CATION	28	Nonword	Block_12
BICK	28	Nonword	Block_12
KEM	28	Nonword	Block_12
SOLOAPS	28	Nonword	Block_12
CHOFIE	28	Nonword	Block_12
PLEVES	28	Nonword	Block_12
SHAWK	28	Nonword	Block_12
SMIECELY	29	Nonword	Block_12
ENFENTS	29	Nonword	Block_12

GWET	29	Nonword	Block_12
GOR	29	Nonword	Block_12
JOLLER	29	Nonword	Block_12
CRE	29	Nonword	Block_12
ULKTION	29	Nonword	Block_12
ORFUL	29	Nonword	Block_12
ZIMP	30	Nonword	Block_12
CRE	30	Nonword	Block_12
GANC	30	Nonword	Block_12
TOINER	30	Nonword	Block_12
MILLOTE	30	Nonword	Block_12
CRE	30	Nonword	Block_12
QUATED	30	Nonword	Block_12
OLROSS	30	Nonword	Block_12

Sentence localizer stimuli run 2 (day 1)

Word	Item_No.	Condition	Block
CRE	31	Nonword	Block_1
GOR	31	Nonword	Block_1
GRART	31	Nonword	Block_1
EP	31	Nonword	Block_1
MEENEL	31	Nonword	Block_1
OMOULT	31	Nonword	Block_1
SMEBS	31	Nonword	Block_1
LALY	31	Nonword	Block_1
U	32	Nonword	Block_1
SWOM	32	Nonword	Block_1
WABEED	32	Nonword	Block_1
NUPP	32	Nonword	Block_1
TUPING	32	Nonword	Block_1
GECLY	32	Nonword	Block_1
SKUSED	32	Nonword	Block_1
HALC	32	Nonword	Block_1
OV	33	Nonword	Block_1
DOZ	33	Nonword	Block_1
KNUDED	33	Nonword	Block_1
THWOOL	33	Nonword	Block_1
CRAFERS	33	Nonword	Block_1
OLP	33	Nonword	Block_1
RHIZ	33	Nonword	Block_1
MELOYSE	33	Nonword	Block_1

DAS	34	Nonword	Block_1
ZOLVEHOOD	34	Nonword	Block_1
DIPY	34	Nonword	Block_1
U	34	Nonword	Block_1
ROWN	34	Nonword	Block_1
SELUE	34	Nonword	Block_1
FLOOP	34	Nonword	Block_1
SHROWER	34	Nonword	Block_1
APPY	35	Nonword	Block_1
CHO	35	Nonword	Block_1
BIZBY	35	Nonword	Block_1
LY	35	Nonword	Block_1
DATION	35	Nonword	Block_1
TWOUT	35	Nonword	Block_1
SWIF	35	Nonword	Block_1
SKEC	35	Nonword	Block_1
THE	31	Sentence	Block_2
SQUIRREL	31	Sentence	Block_2
GRABBED	31	Sentence	Block_2
THE	31	Sentence	Block_2
NUT	31	Sentence	Block_2
AND	31	Sentence	Block_2
RAN	31	Sentence	Block_2
AWAY	31	Sentence	Block_2
THE	32	Sentence	Block_2
GIRLS	32	Sentence	Block_2
RUN	32	Sentence	Block_2
TWO	32	Sentence	Block_2
MILES	32	Sentence	Block_2
ON	32	Sentence	Block_2
TUESDAY	32	Sentence	Block_2
MORNINGS	32	Sentence	Block_2
THE	33	Sentence	Block_2
NEAREST	33	Sentence	Block_2
TOWN	33	Sentence	Block_2
IS	33	Sentence	Block_2
LARGER	33	Sentence	Block_2
THAN	33	Sentence	Block_2
THIS	33	Sentence	Block_2
ONE	33	Sentence	Block_2
THE	34	Sentence	Block_2

SIGN	34	Sentence	Block_2
SAYS	34	Sentence	Block_2
THAT	34	Sentence	Block_2
WE	34	Sentence	Block_2
CANNOT	34	Sentence	Block_2
PASS	34	Sentence	Block_2
HERE	34	Sentence	Block_2
THE	35	Sentence	Block_2
WITCH	35	Sentence	Block_2
RODE	35	Sentence	Block_2
ON	35	Sentence	Block_2
THE	35	Sentence	Block_2
BROOMSTICK	35	Sentence	Block_2
AT	35	Sentence	Block_2
MIDNIGHT	35	Sentence	Block_2
SUSAN	36	Sentence	Block_3
PLAYED	36	Sentence	Block_3
THE	36	Sentence	Block_3
GUITAR	36	Sentence	Block_3
SOLO	36	Sentence	Block_3
DURING	36	Sentence	Block_3
THE	36	Sentence	Block_3
CONCERT	36	Sentence	Block_3
CHARLIE	37	Sentence	Block_3
CLAPPED	37	Sentence	Block_3
FOR	37	Sentence	Block_3
THE	37	Sentence	Block_3
ACTORS	37	Sentence	Block_3
AS	37	Sentence	Block_3
THEY	37	Sentence	Block_3
BOWED	37	Sentence	Block_3
THE	38	Sentence	Block_3
STUDENT	38	Sentence	Block_3
READ	38	Sentence	Block_3
A	38	Sentence	Block_3
BOOK	38	Sentence	Block_3
ABOUT	38	Sentence	Block_3
PIRATE	38	Sentence	Block_3
SHIPS	38	Sentence	Block_3
THE	39	Sentence	Block_3
KID	39	Sentence	Block_3

SEARCHED	39	Sentence	Block_3
FOR	39	Sentence	Block_3
SHELLS	39	Sentence	Block_3
ON	39	Sentence	Block_3
THE	39	Sentence	Block_3
BEACH	39	Sentence	Block_3
MY	40	Sentence	Block_3
AUNT	40	Sentence	Block_3
GAVE	40	Sentence	Block_3
ME	40	Sentence	Block_3
A	40	Sentence	Block_3
PAIR	40	Sentence	Block_3
OF	40	Sentence	Block_3
JEANS	40	Sentence	Block_3
UB	36	Nonword	Block_4
WERN	36	Nonword	Block_4
UF	36	Nonword	Block_4
GNOULED	36	Nonword	Block_4
PHOL	36	Nonword	Block_4
CINTED	36	Nonword	Block_4
CRE	36	Nonword	Block_4
MERB	36	Nonword	Block_4
FE	37	Nonword	Block_4
SHOS	37	Nonword	Block_4
PRENDSDOYCE	37	Nonword	Block_4
UNDAC	37	Nonword	Block_4
TOMEN	37	Nonword	Block_4
EMTO	37	Nonword	Block_4
SOLLY	37	Nonword	Block_4
QUINTER	37	Nonword	Block_4
SNOLFOAT	38	Nonword	Block_4
FIDDER	38	Nonword	Block_4
NER	38	Nonword	Block_4
U	38	Nonword	Block_4
SUV	38	Nonword	Block_4
UB	38	Nonword	Block_4
TUPING	38	Nonword	Block_4
EN	38	Nonword	Block_4
REDEN	39	Nonword	Block_4
CRE	39	Nonword	Block_4
DRAREES	39	Nonword	Block_4

EMEINST	39	Nonword	Block_4
SME	39	Nonword	Block_4
YOLTED	39	Nonword	Block_4
CRE	39	Nonword	Block_4
KUST	39	Nonword	Block_4
NANG	40	Nonword	Block_4
CRE	40	Nonword	Block_4
PRAULED	40	Nonword	Block_4
CRE	40	Nonword	Block_4
UBO	40	Nonword	Block_4
IM	40	Nonword	Block_4
U	40	Nonword	Block_4
FORLOIT	40	Nonword	Block_4
LENKET	41	Nonword	Block_5
VEDER	41	Nonword	Block_5
EMER	41	Nonword	Block_5
TAVS	41	Nonword	Block_5
WRESHED	41	Nonword	Block_5
VEN	41	Nonword	Block_5
WHUSS	41	Nonword	Block_5
CRE	41	Nonword	Block_5
KIVS	42	Nonword	Block_5
NER	42	Nonword	Block_5
NIS	42	Nonword	Block_5
PORLA	42	Nonword	Block_5
TAL	42	Nonword	Block_5
GHEP	42	Nonword	Block_5
YOS	42	Nonword	Block_5
EN	42	Nonword	Block_5
CRE	43	Nonword	Block_5
UB	43	Nonword	Block_5
DAMENTS	43	Nonword	Block_5
MOOMS	43	Nonword	Block_5
TWU	43	Nonword	Block_5
YERVEED	43	Nonword	Block_5
VELNY	43	Nonword	Block_5
UB	43	Nonword	Block_5
PEQUENCE	44	Nonword	Block_5
NER	44	Nonword	Block_5
RECLUDE	44	Nonword	Block_5
NIS	44	Nonword	Block_5

CRE	44	Nonword	Block_5
FO	44	Nonword	Block_5
CRE	44	Nonword	Block_5
BLEECALE	44	Nonword	Block_5
EP	45	Nonword	Block_5
DILBON	45	Nonword	Block_5
CRE	45	Nonword	Block_5
TUY	45	Nonword	Block_5
SWUS	45	Nonword	Block_5
PIFF	45	Nonword	Block_5
CRE	45	Nonword	Block_5
LAS	45	Nonword	Block_5
THE	41	Sentence	Block_6
TWO	41	Sentence	Block_6
FRIENDS	41	Sentence	Block_6
WATCHED	41	Sentence	Block_6
A	41	Sentence	Block_6
MOVIE	41	Sentence	Block_6
LAST	41	Sentence	Block_6
WEEKEND	41	Sentence	Block_6
THE	42	Sentence	Block_6
CLOSEST	42	Sentence	Block_6
PARKING	42	Sentence	Block_6
SPOT	42	Sentence	Block_6
IS	42	Sentence	Block_6
THREE	42	Sentence	Block_6
BLOCKS	42	Sentence	Block_6
AWAY	42	Sentence	Block_6
JESSIE	43	Sentence	Block_6
AND	43	Sentence	Block_6
SAM	43	Sentence	Block_6
PLANTED	43	Sentence	Block_6
SEEDS	43	Sentence	Block_6
NEAR	43	Sentence	Block_6
THEIR	43	Sentence	Block_6
SCHOOL	43	Sentence	Block_6
THE	44	Sentence	Block_6
PILOT	44	Sentence	Block_6
LANDED	44	Sentence	Block_6
THE	44	Sentence	Block_6
AIRPLANE	44	Sentence	Block_6

IN	44	Sentence	Block_6
A	44	Sentence	Block_6
FIELD	44	Sentence	Block_6
THE	45	Sentence	Block_6
ANTS	45	Sentence	Block_6
WALKED	45	Sentence	Block_6
TOWARDS	45	Sentence	Block_6
THE	45	Sentence	Block_6
RED	45	Sentence	Block_6
PICNIC	45	Sentence	Block_6
BLANKET	45	Sentence	Block_6
OLP	46	Nonword	Block_7
EN	46	Nonword	Block_7
FO	46	Nonword	Block_7
SPRA	46	Nonword	Block_7
BLINER	46	Nonword	Block_7
MEF	46	Nonword	Block_7
OLP	46	Nonword	Block_7
ULBS	46	Nonword	Block_7
WOCKER	47	Nonword	Block_7
BEPS	47	Nonword	Block_7
NEPHED	47	Nonword	Block_7
FEFS	47	Nonword	Block_7
CRE	47	Nonword	Block_7
FO	47	Nonword	Block_7
EN	47	Nonword	Block_7
NURFNESS	47	Nonword	Block_7
OLP	48	Nonword	Block_7
EN	48	Nonword	Block_7
UT	48	Nonword	Block_7
PSALCING	48	Nonword	Block_7
PREPE	48	Nonword	Block_7
CHAPE	48	Nonword	Block_7
CRE	48	Nonword	Block_7
STADER'S	48	Nonword	Block_7
ULDIVE	49	Nonword	Block_7
CHO	49	Nonword	Block_7
NICOP	49	Nonword	Block_7
NER	49	Nonword	Block_7
VAKES	49	Nonword	Block_7
CRE	49	Nonword	Block_7

AMKET	49	Nonword	Block_7
CRE	49	Nonword	Block_7
DOICE	50	Nonword	Block_7
OAPER	50	Nonword	Block_7
FREWLY	50	Nonword	Block_7
TROTINE	50	Nonword	Block_7
TWEVE	50	Nonword	Block_7
NOM	50	Nonword	Block_7
FO	50	Nonword	Block_7
EN	50	Nonword	Block_7
CHEYS	51	Nonword	Block_8
OLP	51	Nonword	Block_8
SHLOUGH	51	Nonword	Block_8
FOWSOPE	51	Nonword	Block_8
CRE	51	Nonword	Block_8
EFOUT	51	Nonword	Block_8
CHURNT	51	Nonword	Block_8
AYT	51	Nonword	Block_8
CRE	52	Nonword	Block_8
IM	52	Nonword	Block_8
FRISO	52	Nonword	Block_8
ZIE	52	Nonword	Block_8
LY	52	Nonword	Block_8
IM	52	Nonword	Block_8
SANOR	52	Nonword	Block_8
FO	52	Nonword	Block_8
CRE	53	Nonword	Block_8
LOZERS	53	Nonword	Block_8
SCRALF	53	Nonword	Block_8
CRE	53	Nonword	Block_8
URE	53	Nonword	Block_8
SOUMP	53	Nonword	Block_8
CULKED	53	Nonword	Block_8
JUBED	53	Nonword	Block_8
CRE	54	Nonword	Block_8
QUONET	54	Nonword	Block_8
CRE	54	Nonword	Block_8
NUPP	54	Nonword	Block_8
OLP	54	Nonword	Block_8
MERCH	54	Nonword	Block_8
GLUB	54	Nonword	Block_8

U	54	Nonword	Block_8
IM	55	Nonword	Block_8
CRE	55	Nonword	Block_8
RICAL	55	Nonword	Block_8
GLAY	55	Nonword	Block_8
FO	55	Nonword	Block_8
CHO	55	Nonword	Block_8
IM	55	Nonword	Block_8
CRE	55	Nonword	Block_8
MARK	46	Sentence	Block_9
PACKED	46	Sentence	Block_9
AN	46	Sentence	Block_9
APPLE	46	Sentence	Block_9
AND	46	Sentence	Block_9
A	46	Sentence	Block_9
HAM	46	Sentence	Block_9
SANDWICH	46	Sentence	Block_9
THE	47	Sentence	Block_9
PARENTS	47	Sentence	Block_9
BOUGHT	47	Sentence	Block_9
A	47	Sentence	Block_9
BRAND	47	Sentence	Block_9
NEW	47	Sentence	Block_9
BABY	47	Sentence	Block_9
CARRIAGE	47	Sentence	Block_9
THE	48	Sentence	Block_9
RED	48	Sentence	Block_9
BALLOON	48	Sentence	Block_9
ROSE	48	Sentence	Block_9
UP	48	Sentence	Block_9
INTO	48	Sentence	Block_9
THE	48	Sentence	Block_9
CLOUDS	48	Sentence	Block_9
AMY	49	Sentence	Block_9
CAUGHT	49	Sentence	Block_9
THE	49	Sentence	Block_9
BALL	49	Sentence	Block_9
AND	49	Sentence	Block_9
THREW	49	Sentence	Block_9
IT	49	Sentence	Block_9
BACK	49	Sentence	Block_9

THE	50	Sentence	Block_9
BEAR	50	Sentence	Block_9
CUB	50	Sentence	Block_9
STAYED	50	Sentence	Block_9
CLOSE	50	Sentence	Block_9
TO	50	Sentence	Block_9
HIS	50	Sentence	Block_9
SISTERS	50	Sentence	Block_9
DAD	51	Sentence	Block_10
WAS	51	Sentence	Block_10
TIRED	51	Sentence	Block_10
SO	51	Sentence	Block_10
HE	51	Sentence	Block_10
TOOK	51	Sentence	Block_10
A	51	Sentence	Block_10
NAP	51	Sentence	Block_10
THE	52	Sentence	Block_10
NEIGHBOR	52	Sentence	Block_10
RANG	52	Sentence	Block_10
THE	52	Sentence	Block_10
DOORBELL	52	Sentence	Block_10
TO	52	Sentence	Block_10
GET	52	Sentence	Block_10
INSIDE	52	Sentence	Block_10
THE	53	Sentence	Block_10
BIRD	53	Sentence	Block_10
PERCHED	53	Sentence	Block_10
ON	53	Sentence	Block_10
THE	53	Sentence	Block_10
BRANCH	53	Sentence	Block_10
AND	53	Sentence	Block_10
SANG	53	Sentence	Block_10
EVA	54	Sentence	Block_10
PLACED	54	Sentence	Block_10
A	54	Sentence	Block_10
SECRET	54	Sentence	Block_10
MESSAGE	54	Sentence	Block_10
IN	54	Sentence	Block_10
A	54	Sentence	Block_10
BOTTLE	54	Sentence	Block_10
JACK	55	Sentence	Block_10

FILLED	55	Sentence	Block_10
THE	55	Sentence	Block_10
BOWL	55	Sentence	Block_10
WITH	55	Sentence	Block_10
NOODLES	55	Sentence	Block_10
AND	55	Sentence	Block_10
CHICKEN	55	Sentence	Block_10
IM	56	Nonword	Block_11
CRE	56	Nonword	Block_11
UNGEED	56	Nonword	Block_11
SKOICE	56	Nonword	Block_11
FO	56	Nonword	Block_11
THUSS	56	Nonword	Block_11
BLOIL	56	Nonword	Block_11
CRE	56	Nonword	Block_11
SNAS	57	Nonword	Block_11
MERLY	57	Nonword	Block_11
BEWNA	57	Nonword	Block_11
CRE	57	Nonword	Block_11
SOUMP	57	Nonword	Block_11
JILK	57	Nonword	Block_11
CRE	57	Nonword	Block_11
UDD	57	Nonword	Block_11
FO	58	Nonword	Block_11
EN	58	Nonword	Block_11
UTT	58	Nonword	Block_11
ELLNER	58	Nonword	Block_11
CRE	58	Nonword	Block_11
EN	58	Nonword	Block_11
U	58	Nonword	Block_11
SOM	58	Nonword	Block_11
BATHAN	59	Nonword	Block_11
KOUR	59	Nonword	Block_11
CRE	59	Nonword	Block_11
MEEDA	59	Nonword	Block_11
OLMIRLD	59	Nonword	Block_11
TIRGE	59	Nonword	Block_11
FO	59	Nonword	Block_11
GWIZED	59	Nonword	Block_11
LAS	60	Nonword	Block_11
RELVET	60	Nonword	Block_11

OLP	60	Nonword	Block_11
SWID	60	Nonword	Block_11
NER	60	Nonword	Block_11
KNASEING	60	Nonword	Block_11
UB	60	Nonword	Block_11
KOSEED	60	Nonword	Block_11
LIZ	56	Sentence	Block_12
PACKED	56	Sentence	Block_12
HER	56	Sentence	Block_12
OLD	56	Sentence	Block_12
CLOTHES	56	Sentence	Block_12
IN	56	Sentence	Block_12
A	56	Sentence	Block_12
SUITCASE	56	Sentence	Block_12
JAMES	57	Sentence	Block_12
WENT	57	Sentence	Block_12
TO	57	Sentence	Block_12
THE	57	Sentence	Block_12
STORE	57	Sentence	Block_12
TO	57	Sentence	Block_12
BUY	57	Sentence	Block_12
BREAD	57	Sentence	Block_12
EMMA'S	58	Sentence	Block_12
GRANDPA	58	Sentence	Block_12
TOLD	58	Sentence	Block_12
HER	58	Sentence	Block_12
TO	58	Sentence	Block_12
BRUSH	58	Sentence	Block_12
HER	58	Sentence	Block_12
TEETH	58	Sentence	Block_12
THE	59	Sentence	Block_12
BUTTON	59	Sentence	Block_12
FELL	59	Sentence	Block_12
OFF	59	Sentence	Block_12
BUT	59	Sentence	Block_12
HANNAH	59	Sentence	Block_12
FOUND	59	Sentence	Block_12
IT	59	Sentence	Block_12
THE	60	Sentence	Block_12
GIRL	60	Sentence	Block_12
WANTED	60	Sentence	Block_12

A	60	Sentence	Block_12
BIKE	60	Sentence	Block_12
FOR	60	Sentence	Block_12
HER	60	Sentence	Block_12
BIRTHDAY	60	Sentence	Block_12

Sentence localizer stimuli run 1 (day 2)

Word	Item_No.	Condition	Block
THE	61	Sentence	Block_1
CAMEL	61	Sentence	Block_1
AND	61	Sentence	Block_1
MERCHANT	61	Sentence	Block_1
WALKED	61	Sentence	Block_1
THROUGH	61	Sentence	Block_1
THE	61	Sentence	Block_1
DESERT	61	Sentence	Block_1
THE	62	Sentence	Block_1
WHITE	62	Sentence	Block_1
BUNNY	62	Sentence	Block_1
ATE	62	Sentence	Block_1
A	62	Sentence	Block_1
PLATE	62	Sentence	Block_1
OF	62	Sentence	Block_1
CARROTS	62	Sentence	Block_1
THE	63	Sentence	Block_1
CLOCK	63	Sentence	Block_1
STRUCK	63	Sentence	Block_1
TWELVE	63	Sentence	Block_1
AND	63	Sentence	Block_1
JOSH	63	Sentence	Block_1
WENT	63	Sentence	Block_1
HOME	63	Sentence	Block_1
ANDREW	64	Sentence	Block_1
SAT	64	Sentence	Block_1
ON	64	Sentence	Block_1
THE	64	Sentence	Block_1
COUCH	64	Sentence	Block_1
AND	64	Sentence	Block_1
ATE	64	Sentence	Block_1

POPCORN	64	Sentence	Block_1
MOST	65	Sentence	Block_1
PEOPLE	65	Sentence	Block_1
STAYED	65	Sentence	Block_1
INDOORS	65	Sentence	Block_1
DURING	65	Sentence	Block_1
THE	65	Sentence	Block_1
STORMY	65	Sentence	Block_1
NIGHT	65	Sentence	Block_1
THE	66	Sentence	Block_2
CLOWN	66	Sentence	Block_2
AMUSED	66	Sentence	Block_2
THE	66	Sentence	Block_2
CROWD	66	Sentence	Block_2
WITH	66	Sentence	Block_2
MAGIC	66	Sentence	Block_2
TRICKS	66	Sentence	Block_2
THE	67	Sentence	Block_2
FARMER	67	Sentence	Block_2
SOLD	67	Sentence	Block_2
MAGGIE	67	Sentence	Block_2
FIVE	67	Sentence	Block_2
EARS	67	Sentence	Block_2
OF	67	Sentence	Block_2
CORN	67	Sentence	Block_2
THE	68	Sentence	Block_2
KING	68	Sentence	Block_2
AND	68	Sentence	Block_2
QUEEN	68	Sentence	Block_2
PUT	68	Sentence	Block_2
ON	68	Sentence	Block_2
THEIR	68	Sentence	Block_2
CROWNS	68	Sentence	Block_2
SALLY	69	Sentence	Block_2
AND	69	Sentence	Block_2
NICK	69	Sentence	Block_2
HOPPED	69	Sentence	Block_2
OVER	69	Sentence	Block_2
THE	69	Sentence	Block_2
PICKET	69	Sentence	Block_2
FENCE	69	Sentence	Block_2

JONAH	70	Sentence	Block_2
HAD	70	Sentence	Block_2
BLUE	70	Sentence	Block_2
EYES	70	Sentence	Block_2
AND	70	Sentence	Block_2
MESSY	70	Sentence	Block_2
BROWN	70	Sentence	Block_2
HAIR	70	Sentence	Block_2
ZOPEED	61	Nonword	Block_3
CRAYED	61	Nonword	Block_3
OLP	61	Nonword	Block_3
SWIC	61	Nonword	Block_3
TROP	61	Nonword	Block_3
LARP	61	Nonword	Block_3
LINNED	61	Nonword	Block_3
CRE	61	Nonword	Block_3
BOCKER	62	Nonword	Block_3
CRE	62	Nonword	Block_3
DRASK'S	62	Nonword	Block_3
LAS	62	Nonword	Block_3
NIS	62	Nonword	Block_3
CRE	62	Nonword	Block_3
OG	62	Nonword	Block_3
FOUTED	62	Nonword	Block_3
LAS	63	Nonword	Block_3
SAUNTED	63	Nonword	Block_3
FLIV	63	Nonword	Block_3
VAULED	63	Nonword	Block_3
GAING	63	Nonword	Block_3
DRUNDY	63	Nonword	Block_3
LESPEEN	63	Nonword	Block_3
KES	63	Nonword	Block_3
NUPP	64	Nonword	Block_3
RULL	64	Nonword	Block_3
ZACKS	64	Nonword	Block_3
EP	64	Nonword	Block_3
LIN	64	Nonword	Block_3
BOCKNEY	64	Nonword	Block_3
CRE	64	Nonword	Block_3
U	64	Nonword	Block_3
UCONG	65	Nonword	Block_3

PRELLSULT	65	Nonword	Block_3
BEGY	65	Nonword	Block_3
OLOR	65	Nonword	Block_3
CRE	65	Nonword	Block_3
SOM	65	Nonword	Block_3
OLP	65	Nonword	Block_3
SOAFED	65	Nonword	Block_3
TURCY	66	Nonword	Block_4
SWEEM	66	Nonword	Block_4
SNUM	66	Nonword	Block_4
TIFOY	66	Nonword	Block_4
UTT	66	Nonword	Block_4
DWERTHED	66	Nonword	Block_4
CLUPER	66	Nonword	Block_4
DERNER	66	Nonword	Block_4
MINCOM	67	Nonword	Block_4
EN	67	Nonword	Block_4
TRARE	67	Nonword	Block_4
FIRKED	67	Nonword	Block_4
OLLA	67	Nonword	Block_4
UB	67	Nonword	Block_4
UBONGE	67	Nonword	Block_4
LUNER	67	Nonword	Block_4
THUCK	68	Nonword	Block_4
LISENCES	68	Nonword	Block_4
SMUNCHY	68	Nonword	Block_4
BACHEL	68	Nonword	Block_4
CLIZING	68	Nonword	Block_4
CROM	68	Nonword	Block_4
SLAED	68	Nonword	Block_4
TWIM	68	Nonword	Block_4
SWALK	69	Nonword	Block_4
CRE	69	Nonword	Block_4
TROP	69	Nonword	Block_4
JECING	69	Nonword	Block_4
OLP	69	Nonword	Block_4
WHEPS	69	Nonword	Block_4
TOTIONS	69	Nonword	Block_4
CRE	69	Nonword	Block_4
UB	70	Nonword	Block_4
CRE	70	Nonword	Block_4

OLL	70	Nonword	Block_4
VAGE	70	Nonword	Block_4
LOWTHED	70	Nonword	Block_4
ALFER	70	Nonword	Block_4
MILORM	70	Nonword	Block_4
CAMO	70	Nonword	Block_4
THE	71	Sentence	Block_5
BALD	71	Sentence	Block_5
EAGLE	71	Sentence	Block_5
SOARED	71	Sentence	Block_5
THROUGH	71	Sentence	Block_5
THE	71	Sentence	Block_5
CLOUDLESS	71	Sentence	Block_5
SKY	71	Sentence	Block_5
THE	72	Sentence	Block_5
WOODEN	72	Sentence	Block_5
DOLL	72	Sentence	Block_5
LAY	72	Sentence	Block_5
NEAR	72	Sentence	Block_5
THE	72	Sentence	Block_5
TEDDY	72	Sentence	Block_5
BEARS	72	Sentence	Block_5
THE	73	Sentence	Block_5
PEN	73	Sentence	Block_5
WAS	73	Sentence	Block_5
HIDDEN	73	Sentence	Block_5
BEHIND	73	Sentence	Block_5
THE	73	Sentence	Block_5
TORN	73	Sentence	Block_5
NOVEL	73	Sentence	Block_5
THE	74	Sentence	Block_5
BLACK	74	Sentence	Block_5
AND	74	Sentence	Block_5
WHITE	74	Sentence	Block_5
PHOTO	74	Sentence	Block_5
RESTED	74	Sentence	Block_5
CLOSE	74	Sentence	Block_5
BY	74	Sentence	Block_5
BY	75	Sentence	Block_5
TELLING	75	Sentence	Block_5
THE	75	Sentence	Block_5

TRUTH	75	Sentence	Block_5
WE	75	Sentence	Block_5
HURT	75	Sentence	Block_5
MATTHEW'S	75	Sentence	Block_5
FEELINGS	75	Sentence	Block_5
ANNA'S	76	Sentence	Block_6
HAPPY	76	Sentence	Block_6
SHOUTS	76	Sentence	Block_6
ECHOED	76	Sentence	Block_6
LOUDLY	76	Sentence	Block_6
IN	76	Sentence	Block_6
THE	76	Sentence	Block_6
CANYON	76	Sentence	Block_6
BOXES	77	Sentence	Block_6
FILLED	77	Sentence	Block_6
THE	77	Sentence	Block_6
HALLWAY	77	Sentence	Block_6
IN	77	Sentence	Block_6
ZACH'S	77	Sentence	Block_6
NEW	77	Sentence	Block_6
HOUSE	77	Sentence	Block_6
THE	78	Sentence	Block_6
SAILORS	78	Sentence	Block_6
ONSHORE	78	Sentence	Block_6
STARED	78	Sentence	Block_6
OUT	78	Sentence	Block_6
AT	78	Sentence	Block_6
THE	78	Sentence	Block_6
SEA	78	Sentence	Block_6
A	79	Sentence	Block_6
BREEZE	79	Sentence	Block_6
BLEW	79	Sentence	Block_6
JOHN'S	79	Sentence	Block_6
HAIR	79	Sentence	Block_6
ONTO	79	Sentence	Block_6
HIS	79	Sentence	Block_6
FACE	79	Sentence	Block_6
THE	80	Sentence	Block_6
MICE	80	Sentence	Block_6
RAN	80	Sentence	Block_6
THROUGH	80	Sentence	Block_6

THE	80	Sentence	Block_6
KITCHEN	80	Sentence	Block_6
LAST	80	Sentence	Block_6
NIGHT	80	Sentence	Block_6
CILES	71	Nonword	Block_7
CRE	71	Nonword	Block_7
PLOOING	71	Nonword	Block_7
AYT	71	Nonword	Block_7
CUNED	71	Nonword	Block_7
THRYME	71	Nonword	Block_7
GNIRED	71	Nonword	Block_7
LUGSAN	71	Nonword	Block_7
CRE	72	Nonword	Block_7
SHIS	72	Nonword	Block_7
ILM	72	Nonword	Block_7
STRENTIL	72	Nonword	Block_7
TESLY	72	Nonword	Block_7
SOUN	72	Nonword	Block_7
URE	72	Nonword	Block_7
MITH	72	Nonword	Block_7
THENTES	73	Nonword	Block_7
SHOLNORE	73	Nonword	Block_7
VIGREE	73	Nonword	Block_7
UNTALE	73	Nonword	Block_7
BLOAFY	73	Nonword	Block_7
PERLIN	73	Nonword	Block_7
SANORES	73	Nonword	Block_7
U	73	Nonword	Block_7
SWA'S	74	Nonword	Block_7
PRAR	74	Nonword	Block_7
U	74	Nonword	Block_7
OGS	74	Nonword	Block_7
BLAT	74	Nonword	Block_7
PSANS	74	Nonword	Block_7
CIEF	74	Nonword	Block_7
CRE	74	Nonword	Block_7
LAS	75	Nonword	Block_7
UR	75	Nonword	Block_7
HYLE	75	Nonword	Block_7
SCAVEN	75	Nonword	Block_7
U	75	Nonword	Block_7

PSAR	75	Nonword	Block_7
CRE	75	Nonword	Block_7
KIFFS	75	Nonword	Block_7
TIFOY	76	Nonword	Block_8
CRE	76	Nonword	Block_8
CHEB	76	Nonword	Block_8
GNUTH	76	Nonword	Block_8
KAK	76	Nonword	Block_8
LAS	76	Nonword	Block_8
TWISH	76	Nonword	Block_8
PRIGHT	76	Nonword	Block_8
NYMS	77	Nonword	Block_8
NEFFSILE	77	Nonword	Block_8
BLEO'S	77	Nonword	Block_8
UB	77	Nonword	Block_8
CRE	77	Nonword	Block_8
GLIKELY	77	Nonword	Block_8
NER	77	Nonword	Block_8
NYTH	77	Nonword	Block_8
GRUSS	78	Nonword	Block_8
LAPE	78	Nonword	Block_8
GURY	78	Nonword	Block_8
WOCKED	78	Nonword	Block_8
E	78	Nonword	Block_8
PRIR	78	Nonword	Block_8
BLITY	78	Nonword	Block_8
DIMPED	78	Nonword	Block_8
SNYM	79	Nonword	Block_8
PROBY	79	Nonword	Block_8
GROMB	79	Nonword	Block_8
SNIN	79	Nonword	Block_8
DUIS	79	Nonword	Block_8
LINGSOR	79	Nonword	Block_8
DID	79	Nonword	Block_8
KUV	79	Nonword	Block_8
PERE	80	Nonword	Block_8
PRAUTED	80	Nonword	Block_8
LAT	80	Nonword	Block_8
REWA	80	Nonword	Block_8
CRE	80	Nonword	Block_8
WOLEERS	80	Nonword	Block_8

FO	80	Nonword	Block_8
TUD	80	Nonword	Block_8
FRED	81	Sentence	Block_9
THREW	81	Sentence	Block_9
THE	81	Sentence	Block_9
SATIN	81	Sentence	Block_9
SHIRT	81	Sentence	Block_9
INTO	81	Sentence	Block_9
THE	81	Sentence	Block_9
DRYER	81	Sentence	Block_9
JOANNE	82	Sentence	Block_9
TRIES	82	Sentence	Block_9
TO	82	Sentence	Block_9
UPDATE	82	Sentence	Block_9
HER	82	Sentence	Block_9
PLANNER	82	Sentence	Block_9
ON	82	Sentence	Block_9
MONDAYS	82	Sentence	Block_9
ASHLEY	83	Sentence	Block_9
GREW	83	Sentence	Block_9
CARROTS	83	Sentence	Block_9
AND	83	Sentence	Block_9
BEETS	83	Sentence	Block_9
IN	83	Sentence	Block_9
HER	83	Sentence	Block_9
GARDEN	83	Sentence	Block_9
PETER	84	Sentence	Block_9
COULD	84	Sentence	Block_9
NOT	84	Sentence	Block_9
DECIDE	84	Sentence	Block_9
BETWEEEN	84	Sentence	Block_9
MUSTARD	84	Sentence	Block_9
AND	84	Sentence	Block_9
KETCHUP	84	Sentence	Block_9
THE	85	Sentence	Block_9
SUN	85	Sentence	Block_9
WAS	85	Sentence	Block_9
SHINING	85	Sentence	Block_9
AND	85	Sentence	Block_9
THE	85	Sentence	Block_9
SNOW	85	Sentence	Block_9

MELTED	85	Sentence	Block_9
DWEBEES	81	Nonword	Block_10
EP	81	Nonword	Block_10
KNECHE	81	Nonword	Block_10
CREIR	81	Nonword	Block_10
OLP	81	Nonword	Block_10
ERV	81	Nonword	Block_10
SWOEED	81	Nonword	Block_10
OLP	81	Nonword	Block_10
UB	82	Nonword	Block_10
THWUM	82	Nonword	Block_10
NER	82	Nonword	Block_10
NARSH	82	Nonword	Block_10
ERU	82	Nonword	Block_10
NIPE	82	Nonword	Block_10
LERJURE	82	Nonword	Block_10
PHEWTH	82	Nonword	Block_10
GITES	83	Nonword	Block_10
CLOS	83	Nonword	Block_10
POBY	83	Nonword	Block_10
TOZ	83	Nonword	Block_10
CRE	83	Nonword	Block_10
CREIR	83	Nonword	Block_10
SMORTH	83	Nonword	Block_10
FLETCH	83	Nonword	Block_10
CRE	84	Nonword	Block_10
ISKED	84	Nonword	Block_10
KURCH	84	Nonword	Block_10
UB	84	Nonword	Block_10
CRE	84	Nonword	Block_10
SNIRM	84	Nonword	Block_10
SWOAT	84	Nonword	Block_10
RHAPH	84	Nonword	Block_10
NIS	85	Nonword	Block_10
TAD	85	Nonword	Block_10
U	85	Nonword	Block_10
TERLY	85	Nonword	Block_10
FUSKAGE	85	Nonword	Block_10
CRE	85	Nonword	Block_10
PELLO	85	Nonword	Block_10
JOU	85	Nonword	Block_10

UF	86	Nonword	Block_11
PINCOW	86	Nonword	Block_11
FO	86	Nonword	Block_11
CRE	86	Nonword	Block_11
FO	86	Nonword	Block_11
NER	86	Nonword	Block_11
NUPE	86	Nonword	Block_11
OG	86	Nonword	Block_11
SAB	87	Nonword	Block_11
GOS	87	Nonword	Block_11
TROW	87	Nonword	Block_11
HORTED	87	Nonword	Block_11
UF	87	Nonword	Block_11
WHATT	87	Nonword	Block_11
WEZ	87	Nonword	Block_11
CESH	87	Nonword	Block_11
ANC	88	Nonword	Block_11
ASCAN	88	Nonword	Block_11
OLSAIRE	88	Nonword	Block_11
TOL	88	Nonword	Block_11
YAV	88	Nonword	Block_11
DRODING	88	Nonword	Block_11
DIRORS	88	Nonword	Block_11
LUS	88	Nonword	Block_11
CRE	89	Nonword	Block_11
TOMAL	89	Nonword	Block_11
YAL	89	Nonword	Block_11
MESAN	89	Nonword	Block_11
YISKS	89	Nonword	Block_11
BUP	89	Nonword	Block_11
TIB	89	Nonword	Block_11
CHEMED	89	Nonword	Block_11
IM	90	Nonword	Block_11
GUG	90	Nonword	Block_11
TOOVE	90	Nonword	Block_11
CONDIST	90	Nonword	Block_11
SMAT	90	Nonword	Block_11
SMESK	90	Nonword	Block_11
OLP	90	Nonword	Block_11
YOAP	90	Nonword	Block_11
CLASS	86	Sentence	Block_12

WAS	86	Sentence	Block_12
ENDED	86	Sentence	Block_12
EARLY	86	Sentence	Block_12
AFTER	86	Sentence	Block_12
THE	86	Sentence	Block_12
FIRE	86	Sentence	Block_12
ALARM	86	Sentence	Block_12
TOMMY	87	Sentence	Block_12
SHYLY	87	Sentence	Block_12
HELD	87	Sentence	Block_12
LAUREN'S	87	Sentence	Block_12
HAND	87	Sentence	Block_12
AND	87	Sentence	Block_12
LOOKED	87	Sentence	Block_12
DOWN	87	Sentence	Block_12
GRACE'S	88	Sentence	Block_12
EYES	88	Sentence	Block_12
SPARKLED	88	Sentence	Block_12
AND	88	Sentence	Block_12
SHE	88	Sentence	Block_12
SMILED	88	Sentence	Block_12
AT	88	Sentence	Block_12
US	88	Sentence	Block_12
BECKY	89	Sentence	Block_12
HAD	89	Sentence	Block_12
A	89	Sentence	Block_12
RED	89	Sentence	Block_12
WAGON	89	Sentence	Block_12
DURING	89	Sentence	Block_12
HER	89	Sentence	Block_12
CHILDHOOD	89	Sentence	Block_12
PATCHES	90	Sentence	Block_12
OF	90	Sentence	Block_12
SKY	90	Sentence	Block_12
WERE	90	Sentence	Block_12
SEEN	90	Sentence	Block_12
THROUGH	90	Sentence	Block_12
THE	90	Sentence	Block_12
TREES	90	Sentence	Block_12

Sentence localizer stimuli run 2 (day 2)

Word	Item_No.	Condition	Block
WHEEMKET	91	Nonword	Block_1
POY	91	Nonword	Block_1
GLASP	91	Nonword	Block_1
GHAM	91	Nonword	Block_1
GOR	91	Nonword	Block_1
FO	91	Nonword	Block_1
GWAN	91	Nonword	Block_1
GOU	91	Nonword	Block_1
WENINE	92	Nonword	Block_1
VILPA	92	Nonword	Block_1
FO	92	Nonword	Block_1
EN	92	Nonword	Block_1
NIS	92	Nonword	Block_1
WHARB	92	Nonword	Block_1
CRE	92	Nonword	Block_1
U	92	Nonword	Block_1
CRE	93	Nonword	Block_1
LURT	93	Nonword	Block_1
IK	93	Nonword	Block_1
FO	93	Nonword	Block_1
IM	93	Nonword	Block_1
OLPA	93	Nonword	Block_1
LY	93	Nonword	Block_1
PRERG	93	Nonword	Block_1
CRE	94	Nonword	Block_1
FROKE	94	Nonword	Block_1
PIZ	94	Nonword	Block_1
DOLLOM	94	Nonword	Block_1
PHODY	94	Nonword	Block_1
KNIPE	94	Nonword	Block_1
SPEY	94	Nonword	Block_1
FLOOSES	94	Nonword	Block_1
U	95	Nonword	Block_1
SWARBING	95	Nonword	Block_1
VAYLANT	95	Nonword	Block_1
UDD	95	Nonword	Block_1
EN	95	Nonword	Block_1
YIR	95	Nonword	Block_1
OLP	95	Nonword	Block_1

STILK	95	Nonword	Block_1
TRUM	96	Nonword	Block_2
JUSED	96	Nonword	Block_2
SMEN	96	Nonword	Block_2
CRE	96	Nonword	Block_2
KOZ	96	Nonword	Block_2
NER	96	Nonword	Block_2
UDD	96	Nonword	Block_2
THUICK	96	Nonword	Block_2
LAS	97	Nonword	Block_2
GLERE	97	Nonword	Block_2
GLUG	97	Nonword	Block_2
GWOYED	97	Nonword	Block_2
CRE	97	Nonword	Block_2
FRIB	97	Nonword	Block_2
EN	97	Nonword	Block_2
ENLIN	97	Nonword	Block_2
EFOUT	98	Nonword	Block_2
UB	98	Nonword	Block_2
BLIN	98	Nonword	Block_2
FROFS	98	Nonword	Block_2
UDD	98	Nonword	Block_2
SCITE	98	Nonword	Block_2
MEELBEAK	98	Nonword	Block_2
BUES	98	Nonword	Block_2
FO	99	Nonword	Block_2
FIRATE	99	Nonword	Block_2
MITH	99	Nonword	Block_2
UB	99	Nonword	Block_2
FROS	99	Nonword	Block_2
POTH	99	Nonword	Block_2
UR	99	Nonword	Block_2
OTH	99	Nonword	Block_2
FODDED	100	Nonword	Block_2
MISULT	100	Nonword	Block_2
YEVE	100	Nonword	Block_2
SMEN	100	Nonword	Block_2
DINRYS	100	Nonword	Block_2
CRE	100	Nonword	Block_2
JOLFS	100	Nonword	Block_2
GNYNCH	100	Nonword	Block_2

THE	91	Sentence	Block_3
FLOCK	91	Sentence	Block_3
OF	91	Sentence	Block_3
SHEEP	91	Sentence	Block_3
LIVED	91	Sentence	Block_3
NEAR	91	Sentence	Block_3
THE	91	Sentence	Block_3
HILLSIDE	91	Sentence	Block_3
ABBY	92	Sentence	Block_3
WATCHED	92	Sentence	Block_3
THE	92	Sentence	Block_3
WAVES	92	Sentence	Block_3
CRASH	92	Sentence	Block_3
ON	92	Sentence	Block_3
THE	92	Sentence	Block_3
SAND	92	Sentence	Block_3
A	93	Sentence	Block_3
RUSTY	93	Sentence	Block_3
LOCK	93	Sentence	Block_3
WAS	93	Sentence	Block_3
FOUND	93	Sentence	Block_3
IN	93	Sentence	Block_3
THE	93	Sentence	Block_3
DRAWER	93	Sentence	Block_3
THE	94	Sentence	Block_3
SMELL	94	Sentence	Block_3
OF	94	Sentence	Block_3
FRESH	94	Sentence	Block_3
PIZZA	94	Sentence	Block_3
FILLED	94	Sentence	Block_3
THE	94	Sentence	Block_3
ROOM	94	Sentence	Block_3
JOSEPH	95	Sentence	Block_3
REACHED	95	Sentence	Block_3
OVER	95	Sentence	Block_3
TO	95	Sentence	Block_3
TOUCH	95	Sentence	Block_3
THE	95	Sentence	Block_3
VELVET	95	Sentence	Block_3
CHAIR	95	Sentence	Block_3
FRANK	96	Sentence	Block_4

DID	96	Sentence	Block_4
NOT	96	Sentence	Block_4
MEAN	96	Sentence	Block_4
TO	96	Sentence	Block_4
SHATTER	96	Sentence	Block_4
THE	96	Sentence	Block_4
VASE	96	Sentence	Block_4
JUDY	97	Sentence	Block_4
SANG	97	Sentence	Block_4
ALONG	97	Sentence	Block_4
WITHOUT	97	Sentence	Block_4
KNOWING	97	Sentence	Block_4
ALL	97	Sentence	Block_4
THE	97	Sentence	Block_4
WORDS	97	Sentence	Block_4
THE	98	Sentence	Block_4
STUDENT	98	Sentence	Block_4
STAYED	98	Sentence	Block_4
UP	98	Sentence	Block_4
TO	98	Sentence	Block_4
FINISH	98	Sentence	Block_4
HER	98	Sentence	Block_4
HOMEWORK	98	Sentence	Block_4
THE	99	Sentence	Block_4
SPIDER	99	Sentence	Block_4
SPUN	99	Sentence	Block_4
ITS	99	Sentence	Block_4
WEB	99	Sentence	Block_4
IN	99	Sentence	Block_4
THE	99	Sentence	Block_4
CORNER	99	Sentence	Block_4
GEORGE	100	Sentence	Block_4
AWOKE	100	Sentence	Block_4
TO	100	Sentence	Block_4
THE	100	Sentence	Block_4
TICKING	100	Sentence	Block_4
OF	100	Sentence	Block_4
HIS	100	Sentence	Block_4
CLOCK	100	Sentence	Block_4
GHUR'S	101	Nonword	Block_5
VIGN	101	Nonword	Block_5

DWUP	101	Nonword	Block_5
CRE	101	Nonword	Block_5
RONK	101	Nonword	Block_5
CALDET	101	Nonword	Block_5
STEZ	101	Nonword	Block_5
ROLT	101	Nonword	Block_5
U	102	Nonword	Block_5
BONSAN	102	Nonword	Block_5
PUBE	102	Nonword	Block_5
RUSSERS	102	Nonword	Block_5
GOMEED	102	Nonword	Block_5
LI	102	Nonword	Block_5
COMTER	102	Nonword	Block_5
CRE	102	Nonword	Block_5
FLONPATE	103	Nonword	Block_5
LAFEING	103	Nonword	Block_5
GOUL	103	Nonword	Block_5
CRE	103	Nonword	Block_5
LAS	103	Nonword	Block_5
UZZ	103	Nonword	Block_5
DERBIST	103	Nonword	Block_5
CRE	103	Nonword	Block_5
GOR	104	Nonword	Block_5
TARBEN	104	Nonword	Block_5
SMOP	104	Nonword	Block_5
CRE	104	Nonword	Block_5
LI	104	Nonword	Block_5
SNIG	104	Nonword	Block_5
CRE	104	Nonword	Block_5
VEFF	104	Nonword	Block_5
CRE	105	Nonword	Block_5
OLP	105	Nonword	Block_5
ZEMP	105	Nonword	Block_5
CHIMN	105	Nonword	Block_5
CRE	105	Nonword	Block_5
LAN	105	Nonword	Block_5
GLISE	105	Nonword	Block_5
NIS	105	Nonword	Block_5
MISLETE	106	Nonword	Block_6
ROWN	106	Nonword	Block_6
UTAR	106	Nonword	Block_6

FO	106	Nonword	Block_6
MITH	106	Nonword	Block_6
KOUR	106	Nonword	Block_6
CRE	106	Nonword	Block_6
IM	106	Nonword	Block_6
OLP	107	Nonword	Block_6
EMER	107	Nonword	Block_6
COLDIST	107	Nonword	Block_6
ZERT	107	Nonword	Block_6
HIEN	107	Nonword	Block_6
LOBLE	107	Nonword	Block_6
CRE	107	Nonword	Block_6
NULO	107	Nonword	Block_6
UL	108	Nonword	Block_6
UB	108	Nonword	Block_6
EXFOY	108	Nonword	Block_6
EMTO	108	Nonword	Block_6
EN	108	Nonword	Block_6
HASE	108	Nonword	Block_6
WEERBY	108	Nonword	Block_6
LONISTS	108	Nonword	Block_6
RECAY	109	Nonword	Block_6
GRAWN	109	Nonword	Block_6
SERG	109	Nonword	Block_6
TAMINTS	109	Nonword	Block_6
PREFOWN	109	Nonword	Block_6
YURT	109	Nonword	Block_6
CRE	109	Nonword	Block_6
BUINT	109	Nonword	Block_6
PHON	110	Nonword	Block_6
BULT	110	Nonword	Block_6
SHLOUGH	110	Nonword	Block_6
BREAMTY	110	Nonword	Block_6
EMOX	110	Nonword	Block_6
CRE	110	Nonword	Block_6
ROP	110	Nonword	Block_6
CRE	110	Nonword	Block_6
A	101	Sentence	Block_7
LEADER	101	Sentence	Block_7
MUST	101	Sentence	Block_7
KNOW	101	Sentence	Block_7

HOW	101	Sentence	Block_7
TO	101	Sentence	Block_7
INSPIRE	101	Sentence	Block_7
OTHERS	101	Sentence	Block_7
ELLA	102	Sentence	Block_7
JUMPED	102	Sentence	Block_7
ON	102	Sentence	Block_7
THE	102	Sentence	Block_7
PILE	102	Sentence	Block_7
OF	102	Sentence	Block_7
CRUNCHY	102	Sentence	Block_7
LEAVES	102	Sentence	Block_7
NOAH	103	Sentence	Block_7
DID	103	Sentence	Block_7
VERY	103	Sentence	Block_7
WELL	103	Sentence	Block_7
BECAUSE	103	Sentence	Block_7
HE	103	Sentence	Block_7
STARTED	103	Sentence	Block_7
EARLY	103	Sentence	Block_7
THE	104	Sentence	Block_7
KIDS	104	Sentence	Block_7
OPENED	104	Sentence	Block_7
THE	104	Sentence	Block_7
DOOR	104	Sentence	Block_7
OF	104	Sentence	Block_7
THE	104	Sentence	Block_7
BIRDCAGE	104	Sentence	Block_7
WATER	105	Sentence	Block_7
QUICKLY	105	Sentence	Block_7
SPEWED	105	Sentence	Block_7
OUT	105	Sentence	Block_7
OF	105	Sentence	Block_7
THE	105	Sentence	Block_7
MERMAID	105	Sentence	Block_7
FOUNTAIN	105	Sentence	Block_7
RACHEL	106	Sentence	Block_8
SLAMMED	106	Sentence	Block_8
THE	106	Sentence	Block_8
CREAKY	106	Sentence	Block_8
SCREEN	106	Sentence	Block_8

DOOR	106	Sentence	Block_8
IN	106	Sentence	Block_8
ANGER	106	Sentence	Block_8
IF	107	Sentence	Block_8
YOU	107	Sentence	Block_8
WORK	107	Sentence	Block_8
HARD	107	Sentence	Block_8
IT	107	Sentence	Block_8
WILL	107	Sentence	Block_8
PAY	107	Sentence	Block_8
OFF	107	Sentence	Block_8
MICHELLE'S	108	Sentence	Block_8
LEGS	108	Sentence	Block_8
ARE	108	Sentence	Block_8
SORE	108	Sentence	Block_8
FROM	108	Sentence	Block_8
PLAYING	108	Sentence	Block_8
TENNIS	108	Sentence	Block_8
TODAY	108	Sentence	Block_8
THE	109	Sentence	Block_8
LAMPSHADE	109	Sentence	Block_8
WAS	109	Sentence	Block_8
PAINTED	109	Sentence	Block_8
WITH	109	Sentence	Block_8
VINES	109	Sentence	Block_8
AND	109	Sentence	Block_8
FLOWERS	109	Sentence	Block_8
KEVIN	110	Sentence	Block_8
BREWED	110	Sentence	Block_8
TEA	110	Sentence	Block_8
AND	110	Sentence	Block_8
POURED	110	Sentence	Block_8
IT	110	Sentence	Block_8
FOR	110	Sentence	Block_8
LILY	110	Sentence	Block_8
TUPING	111	Nonword	Block_9
PISES	111	Nonword	Block_9
YOCKED	111	Nonword	Block_9
MARNING	111	Nonword	Block_9
U	111	Nonword	Block_9
SKAUGE	111	Nonword	Block_9

CRE	111	Nonword	Block_9
WHEEMKET	111	Nonword	Block_9
MEEPLE	112	Nonword	Block_9
SMULFAGE	112	Nonword	Block_9
ZANE	112	Nonword	Block_9
CRE	112	Nonword	Block_9
ETAY	112	Nonword	Block_9
BAPP	112	Nonword	Block_9
GARF	112	Nonword	Block_9
PLOLES	112	Nonword	Block_9
OLP	113	Nonword	Block_9
MUME	113	Nonword	Block_9
U	113	Nonword	Block_9
FORP	113	Nonword	Block_9
TROP	113	Nonword	Block_9
HELF	113	Nonword	Block_9
CRE	113	Nonword	Block_9
CRINKY	113	Nonword	Block_9
CRE	114	Nonword	Block_9
U	114	Nonword	Block_9
MEVY'S	114	Nonword	Block_9
VAFF	114	Nonword	Block_9
BOIN	114	Nonword	Block_9
DOOFNALD	114	Nonword	Block_9
CRE	114	Nonword	Block_9
GINT	114	Nonword	Block_9
OLP	115	Nonword	Block_9
FOINTAIR	115	Nonword	Block_9
DECONDS	115	Nonword	Block_9
FUCE	115	Nonword	Block_9
CRE	115	Nonword	Block_9
U	115	Nonword	Block_9
CRE	115	Nonword	Block_9
ETAY	115	Nonword	Block_9
PAUL	111	Sentence	Block_10
CARVED	111	Sentence	Block_10
BATS	111	Sentence	Block_10
AND	111	Sentence	Block_10
GHOSTS	111	Sentence	Block_10
INTO	111	Sentence	Block_10
THE	111	Sentence	Block_10

PUMPKIN	111	Sentence	Block_10
THE	112	Sentence	Block_10
FLAME	112	Sentence	Block_10
BURNED	112	Sentence	Block_10
BRIGHTLY	112	Sentence	Block_10
UNTIL	112	Sentence	Block_10
THE	112	Sentence	Block_10
CANDLE	112	Sentence	Block_10
MELTED	112	Sentence	Block_10
LESLIE'S	113	Sentence	Block_10
EARRINGS	113	Sentence	Block_10
COULD	113	Sentence	Block_10
BE	113	Sentence	Block_10
SEEN	113	Sentence	Block_10
ACROSS	113	Sentence	Block_10
THE	113	Sentence	Block_10
ROOM	113	Sentence	Block_10
DAN	114	Sentence	Block_10
PLACED	114	Sentence	Block_10
THE	114	Sentence	Block_10
DISH	114	Sentence	Block_10
WITH	114	Sentence	Block_10
CHERRIES	114	Sentence	Block_10
NEAR	114	Sentence	Block_10
BRIAN	114	Sentence	Block_10
TWO	115	Sentence	Block_10
SWANS	115	Sentence	Block_10
WALKED	115	Sentence	Block_10
ALONG	115	Sentence	Block_10
THE	115	Sentence	Block_10
EDGE	115	Sentence	Block_10
OF	115	Sentence	Block_10
WATER	115	Sentence	Block_10
THE	116	Sentence	Block_11
DAISIES	116	Sentence	Block_11
RESTED	116	Sentence	Block_11
ON	116	Sentence	Block_11
TOP	116	Sentence	Block_11
OF	116	Sentence	Block_11
THE	116	Sentence	Block_11
COUNTER	116	Sentence	Block_11

TASHA	117	Sentence	Block_11
WON	117	Sentence	Block_11
A	117	Sentence	Block_11
PRIZE	117	Sentence	Block_11
FOR	117	Sentence	Block_11
HER	117	Sentence	Block_11
WRITING	117	Sentence	Block_11
TALENTS	117	Sentence	Block_11
I	118	Sentence	Block_11
NEED	118	Sentence	Block_11
PENCILS	118	Sentence	Block_11
PENS	118	Sentence	Block_11
AND	118	Sentence	Block_11
PAPER	118	Sentence	Block_11
TO	118	Sentence	Block_11
WORK	118	Sentence	Block_11
LENNY	119	Sentence	Block_11
CURLED	119	Sentence	Block_11
UP	119	Sentence	Block_11
IN	119	Sentence	Block_11
BED	119	Sentence	Block_11
AND	119	Sentence	Block_11
FELL	119	Sentence	Block_11
ASLEEP	119	Sentence	Block_11
THE	120	Sentence	Block_11
SPY	120	Sentence	Block_11
WAS	120	Sentence	Block_11
SENT	120	Sentence	Block_11
TO	120	Sentence	Block_11
GATHER	120	Sentence	Block_11
PRIVATE	120	Sentence	Block_11
DATA	120	Sentence	Block_11
CRE	116	Nonword	Block_12
ULP	116	Nonword	Block_12
NER	116	Nonword	Block_12
ROOPTISE	116	Nonword	Block_12
CRE	116	Nonword	Block_12
RICKOT	116	Nonword	Block_12
BULPED	116	Nonword	Block_12
CRE	116	Nonword	Block_12
UR	117	Nonword	Block_12

SCIVINGS	117	Nonword	Block_12
LAS	117	Nonword	Block_12
ENGE	117	Nonword	Block_12
FLUIBED	117	Nonword	Block_12
AROOPED	117	Nonword	Block_12
CRE	117	Nonword	Block_12
U	117	Nonword	Block_12
OLP	118	Nonword	Block_12
EFUNE	118	Nonword	Block_12
OWSEORS	118	Nonword	Block_12
BUISE	118	Nonword	Block_12
VAG	118	Nonword	Block_12
GERT	118	Nonword	Block_12
CRE	118	Nonword	Block_12
GOR	118	Nonword	Block_12
UF	119	Nonword	Block_12
PISC	119	Nonword	Block_12
CRULB	119	Nonword	Block_12
UB	119	Nonword	Block_12
FOWTH	119	Nonword	Block_12
NIS	119	Nonword	Block_12
GAIF	119	Nonword	Block_12
CUMP	119	Nonword	Block_12
CRE	120	Nonword	Block_12
NER	120	Nonword	Block_12
CRE	120	Nonword	Block_12
WIVE	120	Nonword	Block_12
SHREM	120	Nonword	Block_12
PHEMES	120	Nonword	Block_12
ERUSS	120	Nonword	Block_12
YAIM	120	Nonword	Block_12

Emotion localizer stimuli (both days)

Word	**Block**	**EMOTION_CLASS**
ACTIVATE	1	Neutral_Valence
BENCH	1	Neutral_Valence
CLIFF	1	Neutral_Valence
CURTAINS	1	Neutral_Valence
FORK	1	Neutral_Valence
INDUSTRY	1	Neutral_Valence
LAWN	1	Neutral_Valence

METAL	1	Neutral_Valence
PAINT	1	Neutral_Valence
RADIATOR	1	Neutral_Valence
SEAT	1	Neutral_Valence
TABLE	1	Neutral_Valence
ACCEPTANCE	2	Positive_Valence
AROUSED	2	Positive_Valence
CHAMPION	2	Positive_Valence
ENJOYMENT	2	Positive_Valence
GIFT	2	Positive_Valence
IMPROVE	2	Positive_Valence
LEADER	2	Positive_Valence
MOTHER	2	Positive_Valence
PROMOTION	2	Positive_Valence
SECURE	2	Positive_Valence
SWEETHEART	2	Positive_Valence
UNTROUBLED	2	Positive_Valence
ABUSE	3	Negative_Valence
BOMB	3	Negative_Valence
DEFEATED	3	Negative_Valence
DISGUSTED	3	Negative_Valence
FEARFUL	3	Negative_Valence
HELPLESS	3	Negative_Valence
JAIL	3	Negative_Valence
NIGHTMARE	3	Negative_Valence
REJECTED	3	Negative_Valence
SLAUGHTER	3	Negative_Valence
TERRIFIED	3	Negative_Valence
TROUBLED	3	Negative_Valence
ALLEY	4	Neutral_Valence
BOOK	4	Neutral_Valence
CLOCK	4	Neutral_Valence
DETAIL	4	Neutral_Valence
GENDER	4	Neutral_Valence
INHABITANT	4	Neutral_Valence
LIGHTNING	4	Neutral_Valence
MONTH	4	Neutral_Valence
PAMPHLET	4	Neutral_Valence
RAIN	4	Neutral_Valence
SHADOW	4	Neutral_Valence
TAXI	4	Neutral_Valence

AFRAID	5	Negative_Valence
BURDENED	5	Negative_Valence
DEPRESSION	5	Negative_Valence
DISLOYAL	5	Negative_Valence
FILTH	5	Negative_Valence
HOSTAGE	5	Negative_Valence
KILLER	5	Negative_Valence
PARALYSIS	5	Negative_Valence
ROTTEN	5	Negative_Valence
SLAVE	5	Negative_Valence
THIEF	5	Negative_Valence
ULCER	5	Negative_Valence
ACHIEVEMENT	6	Positive_Valence
BABY	6	Positive_Valence
CHEER	6	Positive_Valence
EXCELLENCE	6	Positive_Valence
GLORY	6	Positive_Valence
INTIMATE	6	Positive_Valence
LIBERTY	6	Positive_Valence
NATURE	6	Positive_Valence
PROUD	6	Positive_Valence
SEXY	6	Positive_Valence
TALENT	6	Positive_Valence
VACATION	6	Positive_Valence
ADMIRED	7	Positive_Valence
BEACH	7	Positive_Valence
CONFIDENT	7	Positive_Valence
EXCITEMENT	7	Positive_Valence
GRADUATE	7	Positive_Valence
JOKE	7	Positive_Valence
LOVE	7	Positive_Valence
OUTSTANDING	7	Positive_Valence
PUPPY	7	Positive_Valence
SNUGGLE	7	Positive_Valence
TERRIFIC	7	Positive_Valence
VALENTINE	7	Positive_Valence
ALONE	8	Negative_Valence
BURIAL	8	Negative_Valence
DESERTER	8	Negative_Valence
DISTRESSED	8	Negative_Valence
FRUSTRATED	8	Negative_Valence

HUMILIATE	8	Negative_Valence
LONELY	8	Negative_Valence
POISON	8	Negative_Valence
RUDE	8	Negative_Valence
SLUM	8	Negative_Valence
TOOTHACHE	8	Negative_Valence
UNHAPPY	8	Negative_Valence
AMBULANCE	9	Negative_Valence
CANCER	9	Negative_Valence
DESPAIRING	9	Negative_Valence
DIVORCE	9	Negative_Valence
FUNERAL	9	Negative_Valence
HURT	9	Negative_Valence
MAD	9	Negative_Valence
POLLUTE	9	Negative_Valence
SAD	9	Negative_Valence
STARVING	9	Negative_Valence
TORTURE	9	Negative_Valence
UPSET	9	Negative_Valence
APPLIANCE	10	Neutral_Valence
BOWL	10	Neutral_Valence
CONCENTRATE	10	Neutral_Valence
ELBOW	10	Neutral_Valence
GLACIER	10	Neutral_Valence
INK	10	Neutral_Valence
LOCKER	10	Neutral_Valence
MUSEUM	10	Neutral_Valence
PASSAGE	10	Neutral_Valence
RATTLE	10	Neutral_Valence
SKEPTICAL	10	Neutral_Valence
TOOL	10	Neutral_Valence
ADORABLE	11	Positive_Valence
BED	11	Positive_Valence
CUDDLE	11	Positive_Valence
FIREWORKS	11	Positive_Valence
HANDSOME	11	Positive_Valence
JOYFUL	11	Positive_Valence
LUCKY	11	Positive_Valence
PARADISE	11	Positive_Valence
RAINBOW	11	Positive_Valence
SPOUSE	11	Positive_Valence

THOUGHTFUL	11	Positive_Valence
VICTORY	11	Positive_Valence
AVENUE	12	Neutral_Valence
BUILDING	12	Neutral_Valence
CONTENTS	12	Neutral_Valence
ELEVATOR	12	Neutral_Valence
GOLFER	12	Neutral_Valence
IRON	12	Neutral_Valence
MACHINE	12	Neutral_Valence
NOISY	12	Neutral_Valence
PENCIL	12	Neutral_Valence
ROCK	12	Neutral_Valence
SPRAY	12	Neutral_Valence
TOWER	12	Neutral_Valence
ANGUISHED	13	Negative_Valence
CRASH	13	Negative_Valence
DESPISE	13	Negative_Valence
DREADFUL	13	Negative_Valence
GLOOM	13	Negative_Valence
ILLNESS	13	Negative_Valence
MALARIA	13	Negative_Valence
POVERTY	13	Negative_Valence
SEASICK	13	Negative_Valence
STENCH	13	Negative_Valence
TOXIC	13	Negative_Valence
USELESS	13	Negative_Valence
ADVENTURE	14	Positive_Valence
BIRTHDAY	14	Positive_Valence
CUTE	14	Positive_Valence
FLIRT	14	Positive_Valence
HAPPY	14	Positive_Valence
KINDNESS	14	Positive_Valence
LUSCIOUS	14	Positive_Valence
PEACE	14	Positive_Valence
RESCUE	14	Positive_Valence
SPRING	14	Positive_Valence
THRILL	14	Positive_Valence
WATERFALL	14	Positive_Valence
BANNER	15	Neutral_Valence
BUS	15	Neutral_Valence
CONTEXT	15	Neutral_Valence

ENGINE	15	Neutral_Valence
HAMMER	15	Neutral_Valence
JELLY	15	Neutral_Valence
MANNER	15	Neutral_Valence
NONSENSE	15	Neutral_Valence
PHASE	15	Neutral_Valence
ROUGH	15	Neutral_Valence
SQUARE	15	Neutral_Valence
TRUCK	15	Neutral_Valence
BARREL	16	Neutral_Valence
CABINET	16	Neutral_Valence
CORD	16	Neutral_Valence
FABRIC	16	Neutral_Valence
HAT	16	Neutral_Valence
JOURNAL	16	Neutral_Valence
MARKET	16	Neutral_Valence
NURSERY	16	Neutral_Valence
POSTER	16	Neutral_Valence
RUNNER	16	Neutral_Valence
STORM	16	Neutral_Valence
UMBRELLA	16	Neutral_Valence
AFFECTION	17	Positive_Valence
CAREFREE	17	Positive_Valence
DIAMOND	17	Positive_Valence
FOOD	17	Positive_Valence
HOLIDAY	17	Positive_Valence
KISS	17	Positive_Valence
MERRY	17	Positive_Valence
PILLOW	17	Positive_Valence
RICHES	17	Positive_Valence
SUCCESS	17	Positive_Valence
TREASURE	17	Positive_Valence
WEDDING	17	Positive_Valence
ASSAULT	18	Negative_Valence
CRUEL	18	Negative_Valence
DISAPPOINT	18	Negative_Valence
DROWN	18	Negative_Valence
HARDSHIP	18	Negative_Valence
INFECTION	18	Negative_Valence
MISERY	18	Negative_Valence
PRISON	18	Negative_Valence

SELFISH	18	Negative_Valence
STRESS	18	Negative_Valence
TRAGEDY	18	Negative_Valence
VICTIM	18	Negative_Valence
BASKET	19	Neutral_Valence
CELLAR	19	Neutral_Valence
CORNER	19	Neutral_Valence
FARM	19	Neutral_Valence
HEADLIGHT	19	Neutral_Valence
KETTLE	19	Neutral_Valence
MATERIAL	19	Neutral_Valence
OBEY	19	Neutral_Valence
PRAIRIE	19	Neutral_Valence
SALAD	19	Neutral_Valence
STOVE	19	Neutral_Valence
UTENSIL	19	Neutral_Valence
BATHROOM	20	Neutral_Valence
CHAIR	20	Neutral_Valence
CORRIDOR	20	Neutral_Valence
FINGER	20	Neutral_Valence
HYDRANT	20	Neutral_Valence
KNOT	20	Neutral_Valence
MEDICINE	20	Neutral_Valence
OFFICE	20	Neutral_Valence
QUART	20	Neutral_Valence
SCISSORS	20	Neutral_Valence
STREET	20	Neutral_Valence
WRITER	20	Neutral_Valence
BANKRUPT	21	Negative_Valence
CRUSHED	21	Negative_Valence
DISASTER	21	Negative_Valence
ENRAGED	21	Negative_Valence
HATE	21	Negative_Valence
INSECURE	21	Negative_Valence
MURDERER	21	Negative_Valence
PUNISHMENT	21	Negative_Valence
SHAMED	21	Negative_Valence
SUFFOCATE	21	Negative_Valence
TRAITOR	21	Negative_Valence
VIOLENT	21	Negative_Valence
BETRAY	22	Negative_Valence

DEATH	22	Negative_Valence
DISCOMFORT	22	Negative_Valence
FAILURE	22	Negative_Valence
HEADACHE	22	Negative_Valence
INSULT	22	Negative_Valence
MUTILATE	22	Negative_Valence
REGRETFUL	22	Negative_Valence
SICK	22	Negative_Valence
TERRIBLE	22	Negative_Valence
TRAUMA	22	Negative_Valence
WAR	22	Negative_Valence
ANGEL	23	Positive_Valence
CARESS	23	Positive_Valence
DIPLOMA	23	Positive_Valence
FREE	23	Positive_Valence
HOME	23	Positive_Valence
KNOWLEDGE	23	Positive_Valence
MILLIONAIRE	23	Positive_Valence
PRETTY	23	Positive_Valence
ROMANTIC	23	Positive_Valence
SUNLIGHT	23	Positive_Valence
TRIUMPH	23	Positive_Valence
WIN	23	Positive_Valence
APPLAUSE	24	Positive_Valence
CASH	24	Positive_Valence
ENGAGED	24	Positive_Valence
FRIENDLY	24	Positive_Valence
HUG	24	Positive_Valence
LAUGHTER	24	Positive_Valence
MONEY	24	Positive_Valence
PROGRESS	24	Positive_Valence
SATISFIED	24	Positive_Valence
SUNRISE	24	Positive_Valence
TROPHY	24	Positive_Valence
WISE	24	Positive_Valence