

## Does quantity processing underlie relationality effects in the left Angular Gyrus?

**Introduction** A central goal of cognitive neuroscience is to understand how humans represent our vast conceptual space. One way to divide this space is by the RELATIONALITY of concepts: while *lady* and *cat* describe properties of an individual, *sister* describes a relation between a female and her sibling(s). Thus, we can say, that words can denote relations with different VALENCE —predicates can differ in the number of arguments they expect. For example *woman* is a predicate requiring a single argument (i.e., it names a monadic relation), while *sister* is one that requires two arguments, and thus names a dyadic relation (Barker, 1995). Similarly, in the verbal domain, a *laugh* has only one actor, i.e., it is monadic, while a *greeting* cannot happen without at least two, and is dyadic. Our first experiment asked how relationality is encoded in the brain. Williams et al. (2017) found that a sub-region of the left inferior parietal lobe (spanning the left Angular Gyrus AG; and Supramarginal Gyrus, SMG) was activated more for dyadic relational words like *sister* than for monadic non-relational words like *lady*, independent of both the eventivity of those words and their syntactic category.

While there are several brain regions that are sensitive to argument structure information, none of them are *selectively* sensitive to argument structure information; each is sensitive to many task manipulations and has been involved in a range of cognitive domains. In particular, the left AG has been argued to be a domain-general semantic or conceptual hub (Bonner et al., 2013; Binder and Desai, 2011), sensitive to manipulations from various cognitive domains, like spatial cognition (Spreng 2009), memory retrieval (Kim 2010, Spaniol 2009, i.a.), and mathematics (Pyke et al., 2014; Domahs et al., 2012; Grabner et al., 2007), in addition to language. Furthermore, the left AG is involved in tasks at the intersection of mathematical and language processing: the left AG is activated for verbal mathematical calculation (Dehaene et al. 2003), to number-case agreement violations (Carreriras et al. 2010), and visually presented words marked by morphological plurals (Domahs et al. 2012; but see Blanco-Elorrieta & Pykkänen 2016). Thus, if there were a single function that could provide a unified analysis for the disparate cognitive findings, that function must be sufficiently general and broadly applicable.

If predicates activate their arguments, then dyadic predicates should activate more arguments than monadic ones. Then, it might be possible that argument structure findings converge on mathematical findings, in that the left AG could be representing semantic information about quantity. Under such an analysis, when a participant comprehends a relational noun (e.g., *sister*), s/he might activate representations of two entities; the mental representation of the one(s) who does the slaughtering and the one(s) that get slaughtered. In contrast, when the participant comprehends *lady*, s/he only activates the mental representation of only a single entity. If this is correct, the argument structure valence effects in the left posterior perisylvian cortex (Williams et al., 2017) could be derived from quantity effects. These argument structure findings would, at their core, be findings about whether a predicate activated a mental representation of a plurality of entities or of a single entity. The current study investigates whether semantic information about quantity could underlie the effects of argument structure valence.

**Design** To directly test the possibility that plurality might underly the relationality effects found in (Williams et al., 2017), we designed an experiment (see below) that contrasts plural relational nouns (e.g., *sisters*) with their singular counterparts (e.g., *sister*), as well as contrasting plural non-relational nouns (e.g. *ladies*) with their singular counterparts (e.g., *lady*). There are many potential outcomes: if we find simple main effects of relationality and plurality with the same location and latency, and further, if we uncover an interaction between relationality and plurality factors, then we might think these two

	Noun-biased		Verb-biased		Ambiguous	
	bare	s-	bare	s-	bare	ed-
<b>+Rel.</b>	sister	sisters	adopt	adopts	arrest	arrested
<b>-Rel.</b>	lady	ladies	erupt	erupts	bubble	bubbled

factors share (at least) one underlying process. In this scenario, relational nouns would activate multiple arguments, and consequently pluralizing them might result in a multiplicative or additive increase in left AG activation. We also might discover that these two factors appear in the same location but have different time courses, suggesting that they may not be driven by a unified process.

Given the current design, morphological complexity is a potential confound, so we added a further contrast that varies morphological *s*-marking in a situation where the presence of the affix doesn't correlate with notional plural interpretation. For this, English is an ideal case, since the *-s* suffix that marks plural on nouns can also be used to denote present tense (i.e., habitual) marking for verbs. Thus, we can use an *s*-marked verbal control to verify that any plurality effect is indeed due to notional plurality and not simple morphological complexity, while additionally attempting to replicate the relationality effects discussed above (i.e., that transitive eventive nouns elicit more IAG activity than intransitive ones).

**Habitual and Verb Controls** Some formal semantic accounts of the meaning of *s*-marked verbs take their habitual interpretation to be derived from a plurality of events. Under this sort of analysis, the *s*-marked verb corresponds to an episodic event, which must necessarily take place over multiple episodes (Rimell, 2004; Krifka, 1995; Farkas and Sugioka, 1983; Lawler, 1973). For example, it is possible for *s*-marked verbs to receive habitual interpretation (e.g., *that dog howls*, which tells you that the dog has a habit of howling and has done so on multiple occasions). If this notion of present tense marking is correct, then applying *s*-marking to verbs would also result in a plurality of events, making *s*-marked verbs a less-than-ideal morphological control. Thus, we introduce one further contrast into the design, which varies morphological complexity in verbs, using another inflectional marker—the past tense marker *-ed*—which should not contribute any notion of plurality whatsoever.

Including extra control conditions allows us the flexibility to introduce one more testable contrast into the experiment. In Williams et al. (2017), the second experiment used noun-verb ambiguous words to test the hypothesis that packaging events as nouns. While that experiment uncovered no effect of syntactic category, it did uncover a relationality effect across contexts that biased participants towards analyzing category-ambiguous words as nouns, and in contexts that biased participants towards analyzing them as verbs. However, the question remains as to whether the activation reported in the second experiment of Williams et al. (2017) could be partially driven by the noun-verb ambiguity of the stimuli. In order to address this potential worry, the present experiment varies the extent to which a word is strongly biased towards being interpreted as a noun, a verb, or whether it can be interpreted as either depending on context. To do this, the present experiment will use the two morphologically marked verbal conditions to investigate the contribution of category ambiguity. We will present verb-dominant words with the *s*-marking, and noun-verb ambiguous words with the *ed*-marking.

**Conclusion** In sum, in this talk, we present the results of an experiment that pits number-marking against argument structure processing, by utilizing a 2 x 2 x 3 design that varies a predicate's valence and whether it receives plural marking, with an additional 3-way manipulation of N-V bias. To account for a potential confound with morphological complexity, we include two different controls: one control applies the same *s*-marking to verbs to control for form-based effects; another control applies a different inflectional marking (*-ed*), in case *s*-marked verbs indeed show more activation than expected, due to potential habitual interpretations. This design allows us to test the following hypotheses: (i) whether quantity processing (i.e. notional plurality) underlies the relationality effect (ii) whether habitual interpretation and plurality activate similar brain regions (iii) whether relationality is represented differently in words that are syntactic-category ambiguous.

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