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The neural representation of plural discourse entities

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ABSTRACT

Little is known about the underlying neural structures that mediate the generation and tracking of discourse referents. In two functional magnetic resonance imaging experiments, we examined the neural structures involved in generating and maintaining the representations of multiple referents. Experiment 1 used two-sentence discourses with singular and plural conditions linking back to single or conjoined subjects. In Experiment 2, conjunction type was manipulated in order to keep the number of discourse entities constant across the discourse. Both experiments found greater activation in the superior parietal lobule bilaterally for plural entities relative to singular entities in Experiment 1 and for unconjoined plural entities relative to conjoined plural entities in Experiment 2. This parietal activation suggests that referring to multiple entities evokes multiple representations that need to be integrated and tracked. We discuss these findings in terms of psycholinguistic theories of multiple referent representations.

1. Introduction

Successful language comprehension requires that listeners and readers relate incoming information to previously processed linguistic input (Grosz, Joshi, & Weinstein, 1995; Sanford & Garrod, 1981). The relation between new and previously mentioned information is often established through anaphora, i.e., the subsequent reference to a previously mentioned referent (Ariel, 1990; van Dijk & Kintsch, 1983). The influx of new information in a discourse makes it important for the comprehender to track references quickly and efficiently, and this entails generating and maintaining detailed representations of mentioned referents so that they can be integrated into the discourse model and linked to subsequent repeated references. The salience—i.e., prominence in the discourse model—of a given entity affects how easily this entity can be accessed from memory, and thus the representation and tracking of references requires the management of memory resources (Almor, 1999; Almor & Nair, 2007; Sanford & Garrod, 1981). Our focus in this study is on the differences between singular and plural references. Specifically, we investigate how such plural references are represented in the brain. Before describing our experiments, we will first review theories of plural anaphora, which are based mostly on findings from behavioral studies. Then we will review the extant fMRI literature on reference processing in order to clarify our predictions.

Plural noun phrases (NPs) can be introduced into text and represented in the discourse model in several ways (Albrecht & Clifton, 1998; Moxey, Sanford, Sturt, & Morrow, 2004; Patson & Ferreira, 2009; Sanford & Lockhart, 1990). They can be introduced as a regular plural NP (e.g., *the students*), as a quantified NP (e.g., *the two students*), or as a conjoined NP (e.g., *the student and the teacher*). Sanford and Lockhart (1990) showed that the form of introduction into the discourse influences the likelihood of subsequent plural reference. For example, conjoined NPs consisting of similar singular forms like *the student and the teacher* are more likely to lead to plural grouping than conjoined NPs consisting of mismatching singular forms like *Jim and the teacher*. In addition to the use of a conjoined NP, having discourse entities participate in a joint activity similarly facilitates subsequent plural pronominal reference (Gelormini-Lezama & Almor, 2013; Moxey, Sanford, Wood, & Gintner, 2011).

At least three different theories have been proposed to explain how plural NPs are stored in memory and processed during discourse comprehension. According to one theory (Sanford & Lockhart, 1990), plural referents are represented and accessed in memory as an assemblage, or a collective group or entity (i.e., the group is more readily accessible than individual members). Albrecht and Clifton (1998) found that when a conjoined NP is broken apart by a singular reference (e.g., *Stan and Pam went to the store. She bought milk*), readers take longer to read the second sentence than when the second sentence makes a singular reference

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referring to a singular antecedent (e.g., *Pam went to the store. She bought milk*). Albrecht and Clifton interpreted this delay as reflecting a "conjunction cost" that is incurred when a conjoined NP has to be broken in order to access one of its components. This led Albrecht and Clifton to conclude that conjoined NPs are represented as a single entity or assemblage.

According to a second theory (Johnson-Laird, 1983), plural referents are individuated and represented as distinct atomic tokens. Kaup, Kelter, and Habel (2002) provided evidence that under certain conditions plural entities are represented individually. However, these types of representations are elicited mainly by the use of partitioning plural NPs such as *most of the orphans* or *both*-phrases. Furthermore, atomic tokens seem to be formed as opposed to an assemblage when features of some of the members of a plural entity are specified (Patson & Warren, 2011). Importantly, the atomic-token view can be used to explain Albrecht and Clifton's results, where singular reference to a conjoined entity results in longer reading times not due to a conjunction cost, but rather as a result of the increased difficulty of retrieving a referent from memory due to the larger number of potential referents in the discourse model.

A third theory, combining the principles of the previous two, suggests that conjoined NPs are under certain conditions represented as a set of individuals or tokens *within* an assemblage. This type of representation is known as a Complex Reference Object (CRO) and can be understood to consist of a representation of both a single entity as well as of the individuals within the entity (Barker, 1992; Moxey et al., 2004; Moxey et al., 2011). In an eye-tracking study, Patson and Ferreira (2009) found that participants' parsing strategies of sentences with reciprocal verbs (e.g., *wrestle*) were affected by the type of plural NP in the preceding sentence (i.e., conjoined NPs: *the trainer and the vet*; or definite plural descriptions: *the trainers*) used in the first clause of the sentence. For example: *The trainer and the vet/The trainers were near the swamp. While they wrestled the alligator watched them closely.* The key measure in this study was reading times at the disambiguating region (*watched* in this case), which indicated whether or not the participants were garden-pathed. They found that reading times on the disambiguating region were shorter when the preceding sentence contained a conjoined NP than when it contained a definite plural description. The authors interpreted this as evidence of CRO formation in which the representations of the individuals made the reciprocal interpretation of the verb more likely than the transitive one. They therefore argued that conjoined NPs favor representation in a CRO.

As of yet none of these theories of plural anaphora representation have been tested with the use of neuroimaging techniques, and therefore it is difficult to generate hypotheses about the neural structures involved in such representations. However, there have been a few studies on reference processing that may illuminate this discussion. In addition, plural reference, though a linguistic process, is analogous to other mental operations that are worth considering.

Most pertinent to our present study is Almor, Smith, Bonilha, Fridriksson, and Rorden (2007), who used functional magnetic resonance imaging (fMRI) to study reference processing. They measured participants' hemodynamic responses as they were reading discourses in which repeated reference was made with either a repeated name (e.g., ***Susan*** *is really into animals. The other day* ***Susan*** *gave Betsy a pet hamster.*) or a pronoun (e.g., ***Susan*** *is really into animals. The other day* ***she*** *gave Betsy a pet hamster.*). Participants showed greater activation in temporal and parietal areas (specifically bilateral intraparietal sulcus (IPS), the superior parietal lobule (SPL; BA 7 in particular), and precuneus) in the repeated name condition than in the pronoun condition. Because temporal regions are known to be involved in memory processes (Bookheimer, 2002), Almor et al. attributed the activation in these regions to the activation of multiple memory representations as a result of reading the repeated names. On the other hand, SPL regions have been argued to be involved in the maintenance and integration of multiple representations (Dehaene, Piazza, Pinel, & Cohen, 2003), leading to the conclusion that the parietal activation represents the formation, maintenance and integration of multiple representations resulting from the reading of the repeated names. Inferences regarding these regions will be discussed in more detail below.

Nieuwland, Petersson, and Van Berkum (2007) similarly used fMRI to investigate the neural representation of reference processing (in addition to semantic coherence). This study contained three conditions of interest to the current discussion: referential ambiguity (e.g., *Ronald told Frank that he* ...), failure (*Rose told Emily that he* ...), and coherence (*Ronald told Emily that he* ...). Compared to referential coherence, ambiguity led to fronto-parietal activation, perhaps indicating that participants were engaged in a decision-making process to establish reference. On the other hand, failure compared to coherence, resulted in bilateral parietal activation (including among other areas BA 7), which may be related to an inference resulting in the formation of a new representation (i.e., assuming the anaphor is referring to an unspecified third party) or morpho-syntactic error. In a post hoc analysis the authors divided the subjects into two groups based on self-reported interpretation of sentences in this condition (either a new referent or referential failure). They found that the group interpreting these sentences as referring to a new referent relative to the referential failure group showed greater activation in left BA8 and right dosolateral BA 9/46. Although this would suggest that introducing a new referent into the discourse evokes frontal activity, an alternative explanation is that this reflects explicit decision making in the new referent group. Indeed, in another fMRI study McMillan, Clark, Gunawardena, Ryant, and Grossman (2012) found widespread frontal activity associated with the greater decision-making demands of ambiguous pronominal reference than non-ambiguous pronominal reference. Additionally, the interpretation that Nieuwland et al.'s (2007) parietal activity findings reflect introducing a new referent into the discourse sits well with Almor et al.'s (2007) findings, where the repeated name (associated with the temporary addition of a new discourse entity before it is resolved as being coreferential; Gordon, Grosz, & Gilliom, 1993) is associated with bilateral parietal activation of a similar nature.

The parietal activation in both studies, and especially the SPL, which is not often associated with non-spatial language processing, is of special interest because it suggests that language recruits areas that are specialized for the management of spatial representations for the task of reference tracking in discourse. For example: Beauchamp, Petit, Ellmore, Ingeholm, and Haxby (2001) found that covert shifts of attention activated regions of IPS extending into the SPL; Corbetta, Miezin, Shulman, and Petersen (1993) found activation in BA 7 bilaterally during a spatial attention shifting task; Culham et al. (1998), using a multiple-object tracking task, found activation both in bilateral IPS and BA 7 (see also, Farah, Wong, Monheit, & Morrow, 1989; Shimozaki et al., 2003; Wojuciulik & Kanwisher, 1999). Related to spatial processing and our discussion of plurality, the IPS and SPL have been associated with numerical processing (e.g., Hubbard, Piazza, Pinel, & Dehaene, 2005). Indeed, Dehaene et al. (2003) posited that the function of the SPL (specifically posterior BA 7) is to orient attention along the mental number line (proposed to be within the IPS) and make numerical comparisons (see also, Harvey, Klein, Petridou, & Dumoulin, 2013; Piazza & Izard, 2009). Thus, taking these two related bodies of literature into account, we would expect that if indeed number and space are important to processing plurals, both the IPS and BA 7 would be activated, depending on the nature of the discourse model. First,