

# What is in a name? Spatial brain circuits are used to track discourse references

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Pronouns are commonly used instead of explicitly repeating a name, and, in many cases, we comprehend language faster when pronouns are used instead of repetitive references. This is surprising because pronouns are often ambiguous, whereas repeated names provide precise reference. We used functional MRI to investigate the neural correlates of this paradoxical preference. Reading repeated names elicited more activation than pronouns

in the middle and inferior temporal gyri and intraparietal sulcus. The temporal lobe activation suggests that repeated names but not pronouns evoke multiple representations that have to be integrated. The intraparietal sulcus activation suggests that this integration relies on brain regions used for spatial attention and perceptual integration. *NeuroReport* 18:1215–1219 © 2007 Lippincott Williams & Wilkins.

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## Introduction

Frequently, real-life language involves the exchange of more information than that could fit in one sentence. Consequently, most conversations and texts involve multiple sentences that are coherently linked through the repetition of information [1]. In many cases, the repetition of information is achieved through the use of pronouns, especially when repeated reference is made to information that is already salient and activated in the context of the discourse [2–4]. For example, when a person has been contextually introduced with a proper name, subsequent sentences that refer to the same person may be easier to read if a pronoun is used instead of a repeated proper name. This phenomenon has been labeled the ‘repeated name penalty’ [2] and is typically reflected in longer reading times of sentences similar to the last sentence in the ‘Repeated Name’ version than in the ‘Pronoun’ version in Table 1.

At first glance, the repeated name penalty may appear puzzling as pronouns are often ambiguous, whereas repeated names provide precise reference. In many contexts, nonetheless, pronouns are used more often, read more naturally and processed with greater ease than full unambiguous repeated references [2,3]. We suggest that this phenomenon can offer a unique insight into how the brain processes language and how language has recruited existing brain circuits.

One explanation for why pronouns are preferred over repeated names is that proper names cause an obligatory generation of a new representation separate from the representation of the old information; the two active representations coexist until the representation of the new information is contrasted or integrated with the representation of the old information [5,6]. Models subscribing to this

explanation differ on whether they attribute these processes to specialized linguistic rules [5] or to nonlinguistic processes that are involved in the creation and integration of multiple representations [6,7]. According to the latter view, pronouns provide a way to immediately establish coreference with minimal memory interference [6–8].

Although there is considerable behavioral evidence about the processing of repeated name references and pronouns in discourse [6], there has been no research about the neural circuits underlying these processes. Evidence about specific cortical areas involved in the processing of reference may provide crucial information about how these processes work. Such evidence may also offer insights into the fundamental question of why people use pronouns for repeated reference. Therefore, our aim was to identify brain areas that are differentially activated by pronouns versus repeated names. We reasoned that if linguistic reference relies on nonlinguistic neural networks, the multiple representations generated by repeating a name should manifest in (a) increased activation in memory-related brain areas, most likely in the temporal lobe [9], and (b) areas that are involved in the consolidation and integration of multiple representations, most likely in the parietal lobe [10].

More specifically, we hypothesized that the brain may rely on spatial processing to represent multiple linguistic references as if they were spatially distinct. This hypothesis is motivated by two observations. The first is that many languages use the form of reference to mark both spatial proximity and discourse status. For example, English uses the articles ‘this’ and ‘that’ to distinguish between references to referents that are proximal in space or salient in discourse, and referents that are further away in space or less prominent in the discourse [1,3]. The second

**Table 1** Sample texts with repeated name and pronoun references (adapted from Gordon *et al.* [2])

Repeated name	Pronoun
Susan is really into animals. The other day <u>Susan</u> gave Betsey a pet hamster. <u>Susan</u> reminded <u>Betsey</u> that such hamsters are quite shy and need gentle handling. Does Susan like animals?	Susan is really into animals. The other day <u>she</u> gave Betsey a pet hamster. <u>She</u> reminded <u>Betsey</u> that such hamsters are quite shy and need gentle handling. Does Susan like animals?

Repeated references are underlined here for illustrative purposes but were not underlined during the experiment. The comprehension questions were presented in about one-third of the trials and were used to encourage participants to remain attentive and engaged during the experiment. Participants' accuracy was also used after the experiment to assess whether they were engaged in the task.

observation is based on American Sign Language's use of spatial indices for making reference, similar to how pronouns are used in spoken language [11]. A signer may sign a noun and then point to a certain spot. If the signer wants to refer back to that noun, he or she points again to the same spot. Both observations suggest a link between spatial processes and the processing of reference in language. Evidence supporting this link would indicate that language has relied on spatial brain mechanisms for the representation and processing of multiple referents.

To test the prediction that repeated names elicit excessive processing in nonlanguage areas, we constructed a purely linguistic task aiming to explore the neural basis of the repeated name penalty. We used functional MRI (fMRI) to measure the brain activation of readers as they read texts similar to the sample text in Table 1. Measurement of the brain's hemodynamic response was time-locked to the presentation of the third sentence in each text. This aimed to capture the activation associated with using a pronoun versus a repeated name in a context that is known to elicit the repeated name penalty.

## Methods

### Participants

Twenty-one participants (16 women; age range, 19–34 years; median, 22 years) were enrolled in this study. All participants were native English speakers with normal or corrected-to-normal visual acuity and no history of neurological problems (self-reported). Participants gave their informed consent to participate in this research, under the guidelines of the University of South Carolina institutional review board. Data from five female participants were excluded from the study on the basis of excessive head motion (three) or question-answer accuracy that was not better than chance (two).

### Procedure

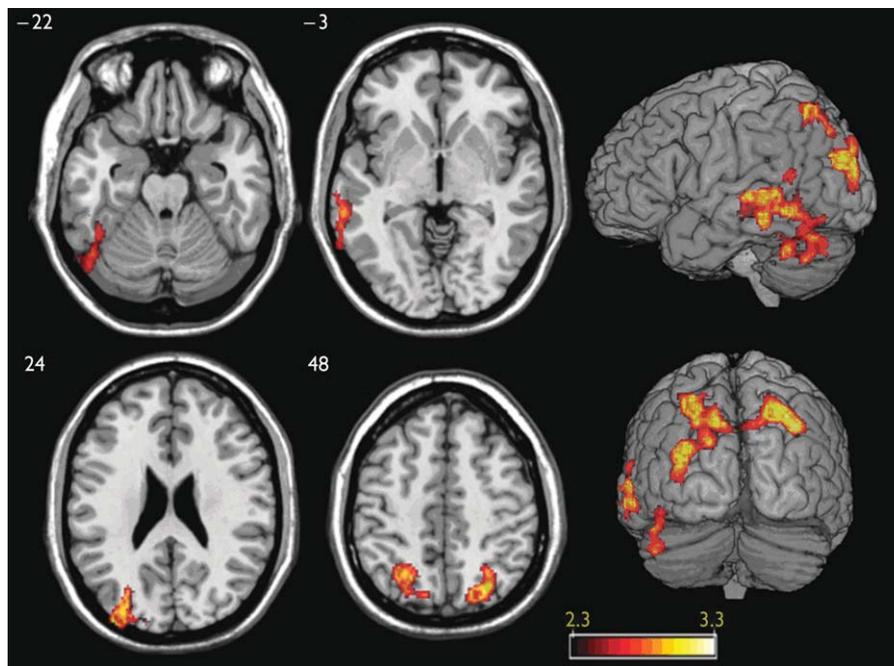
Following explanation of the task requirements, participants underwent two 13-min sessions of fMRI scanning. In each session, participants were asked to read silently sentences that were presented using a back-projection mirror mounted on the MRI head coil and a projection screen located at the end of the scanner bore. Each trial consisted of three sentences presented one at a time, with each sentence displayed in isolation for 4 s. The duration between trials varied from 800 to 3200 ms, reducing the correlation in hemodynamic responses between sentences (i.e., the start of one sentence was not precisely phase-locked to the start of the previous sentence). The stimuli were based on those used in Gordon *et al.* [2]. Sentence 1 introduced one person

who appeared as the grammatical subject in all three sentences. Sentence 2 introduced a second person in the grammatical object position who was less prominent than the first person. In Sentence 3, both entities were referred to and the second person was always referred to by a repeated name. Experimental items appeared in either repeated name or pronoun conditions, in which the first person was referred to by a repeated name or a pronoun in the second sentence and in the crucial third sentence. Each session contained 32 experimental trials mixed with 16 filler trials for a total of 96 trials across the two sessions. The filler trials were also composed of three sentences, but these trials used varied structures and some described only one referent. The role of the filler trials was to reduce participants' expectancy for specific sentence structures, pronouns and repeated names. There were eight intertrial periods of short rest lasting 7.5 s within each session. To reduce predictability, the order of trials was randomly determined with the restriction that each block of seven trials contained one rest period, four experimental trials and two filler trials. The experimental and filler trials were randomly selected. Following about one-third of the trials, participants were given a simple 'yes' or 'no' question regarding the trial they had just read. The question duration was 4.5 s, and participants indicated their response by pressing a button on a Psychology Software Tools, Inc. BrainLogics Fiber Optic Button Response System (Pittsburgh, Pennsylvania, USA) glove placed on their right hand. Participants used the thumb button to indicate a 'yes' response and the index finger button to indicate a 'no' response. The trials with which the questions appeared were selected randomly for each participant resulting in small variations in the number of questions presented to different participants. All participants answered at least 24 questions. The comprehension questions probed information from the trial's text and allowed us to assess whether or not the participant was engaged in the task. Table 1 shows a sample item with a comprehension question.

Scanning was performed on a 3T Siemens Trio scanner (Munich, Germany) equipped with a 12-element head coil. A total of 322 echo-planar imaging (EPI) volumes (36 axial slices; 3.2 mm thick, with no gap between slices) were acquired during each fMRI session. These scans used TR=2.5 s; TE=30 ms; matrix=64 × 64 voxels; flip angle=90°, 208 × 208 mm FOV.

### MRI analyses

Preprocessing and statistical analyses of EPI data were carried out using FEAT (fMRI Expert Analysis Tool) Version 5.43, part of FSL 3.2 (FMRIB's Software Library,



**Fig. 1** Brain areas that were more activated in the repeated name compared with the pronoun condition (threshold:  $Z > 2.3$ , corrected cluster threshold  $P < 0.05$ ). Activation is shown in neurological convention (with the left side of the brain appearing on the left of the image).

*www.fmrib.ox.ac.uk/fsl*). Lower-level analyses implemented motion correction [12]; preserving the skull [13]; spatial smoothing using a Gaussian kernel of FWHM 8 mm; mean-based intensity normalization of all volumes by the same factor and high-pass temporal filtering (Gaussian-weighted LSF straight line fitting, with  $\sigma = 50.0$  s). Time-series statistical analysis was carried out with local autocorrelation correction [14]. All EPI images were normalized in Montreal Neurological Institute space [12,15]. Each participant's cortical activity was measured, as an event-related design, for the two different experimental conditions: processing pronouns or repeated names. Therefore, we quantified the blood oxygen-level dependent signal, convolved with a  $\gamma$ -hemodynamic response function that was observed by the presentation of the third sentence in each trial (when the first person was referred to by a repeated name or a pronoun). For each participant, contrasts were set to evaluate the mean activation related to each condition (repeated name or pronoun) and to compare the activation between the two conditions.  $Z$  (Gaussianized T/F) statistic images were generated using a cluster threshold of  $Z > 2.3$ , and a (corrected) cluster significance threshold of  $P < 0.05$  was adopted.

The group mean cortical activation (higher level analysis) was then calculated by investigating the mean activation for each participant across different trials, and the mean activation between different participants. The higher-level analyses combined sessions and then participants. The intermediate cross-session within participant analysis utilized FMRIB's local analysis of mixed effects stage 1 only, which does not implement Metropolis-Hastings Markov Chain Monte Carlo (MH MCMC) sampling on near-threshold voxels because the final variance cannot be known at an intermediate stage of analysis [16,17]. The final cross-participants analysis used FMRIB's local analysis of

mixed effects stage 1 and 2, in which all voxels that are close to threshold (according to the selected contrasts and thresholds) are processed with a much more sophisticated estimation process involving implicit estimation of the mixed effects variance, using MH MCMC sampling to give the distribution for higher-level contrasts of parameter estimates, to which a general  $t$ -distribution is then fit [16,17].

$Z$ -statistic images were generated using a cluster threshold of  $Z > 2.3$  and a (corrected using Gaussian random field theory) cluster significance threshold of  $P < 0.05$  [18]. MRICro was utilized to display mean statistical maps on a standard brain template, [19] and the anatomical location of significant activation was confirmed with the Talairach Daemon client, using the Talairach coordinates of local maxima [20].

## Results

No differences were present between the conditions in comprehension questions accuracy,  $t(15) = 0.30$ , or in correct answers response time,  $t(15) = 0.45$ , indicating that differences in the blood-oxygen-level dependent signal between the two conditions do not reflect comprehension differences in the two conditions. We identified brain areas that showed a significant increase in signal following a repeated name compared with the use of a pronoun. The repeated name condition led to more activation in the areas around the left and right intraparietal sulcus (IPS), specifically the superior parietal lobule and the precuneus, left fusiform gyrus and left middle and inferior temporal gyri (Fig. 1). Table 2 delineates these brain regions and the related statistics. No areas were significantly more active in the pronoun condition than the repeated name condition.

**Table 2** Brain areas that were more activated in the Repeated Name condition than in the Pronoun condition

Equivalent Z	MNI spatial coordinates			Anatomical location		
	X	Y	Z	Side	Location	Brodman area (BA)
3.31	32	-72	44	Right	Superior parietal lobule	BA 7
3.23	26	-70	46	Right	Superior parietal lobule	BA 7
3.23	38	-72	38	Right	Precuneus	BA 19
3.19	-26	-60	54	Left	Superior parietal lobule	BA 7
3.17	-20	-58	50	Left	Precuneus	BA 7
3.17	30	-64	42	Right	Precuneus	BA 19
3.17	-56	-34	-10	Left	Middle temporal gyrus	BA 20
3.16	-62	-42	2	Left	Middle temporal gyrus	BA 21
3.14	-50	-36	-18	Left	Fusiform gyrus	BA 20
3.12	-50	-38	-14	Left	Middle temporal gyrus	BA 37
3.12	-54	-34	-14	Left	Inferior temporal gyrus	BA 20
3.1	-62	-36	4	Left	Middle temporal gyrus	BA 22

Threshold:  $Z > 2.3$ , cluster threshold  $P$  (corrected for multiple comparisons) = 0.05.  
MNI, Montreal Neurological Institute.

## Discussion

Our finding of increased modulation of the superior parietal lobule, in association with repeating a name, suggests that language relies on nonlinguistic brain circuits. The superior parietal lobule has been consistently implicated in spatial processing [21,22] and perceptual binding [10,21,22]. Generally, activation around the IPS appears to increase when separate representations are activated and are then consolidated in visual perception [21], auditory perception [10], spatial tasks [21,22], temporal tasks [22] and numerical operations [23,24]. Noting that these regions are activated by tasks that require attention to both space and quantities, Hubbard *et al.* [24] suggested that these regions are involved in attentional selection along the spatial dimension and also any other dimension that the brain considers analogous to space, such as time [22] or number [23]. Cusack [10] also suggested that these areas are responsible for amodal perceptual organization and for the binding of different features together into coherent percepts. Our results suggest that language has taken advantage of these functions and that these areas are used by language for the representation of referents in discourse and for the consolidation of multiple representations that is necessary for establishing that two expressions refer to the same thing. We, therefore, interpret the finding of the bilateral IPS activation as evidence that the use of repeated name references involves multiple representations that need to be integrated and bound.

Our findings also support the idea that the generation of multiple representations plays a role in the repeated name penalty. In particular, we observed that the lateral temporal lobe was more actively enrolled in processing names than pronouns. The middle temporal gyrus subserves a variety of semantic processes [9]. Increased activation in semantic processing regions suggests that repeating the name may increase the semantic coding burden, possibly reflecting the generation of a new representation [5,7].

The finding of lesser activation in the temporal and IPS regions for pronouns relative to repeated names suggests that pronouns do not require the same amount of consolidation and feature binding that repeated names do. This suggests that pronouns are a linguistic device that language developed to reduce interference and to lessen the

processing effort required for the consolidation of multiple representations.

Overall, these findings support our hypothesis that the brain relies on spatial processing to represent multiple linguistic references as if they were spatially distinct. We further speculate that pronouns may be the solution that language invented to meet the challenge of sequential communication with a limited capacity memory system, rather than an arbitrary aspect of the grammar of language. In this view, pronouns reduce representational burden by picking referents directly, as is most clearly evident in the case of American sign language.

## Conclusion

Our findings suggest that at least some aspects of language evolved by adapting preexisting brain circuitry. We speculate that language has taken advantage of the function of areas that allow us to track multiple visual objects and commandeered them for the representation of referents in discourse. This may reflect the fact that, for most of human history, personal interactions occurred in a three-dimensional spatial environment, resulting in an intrinsic link between reference and locus in space.

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