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# The contribution of fronto-parietal regions to sentence comprehension: Insights from the Moses illusion

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ABSTRACT

To interpret a sentence, the reader must not only process the linguistic input, but many times has also to draw inferences about what is implicitly stated. In some cases, the generation and integration of inferred information may lead to semantic illusions. In these sentences, subjects fail to detect errors such as in "It was two animals of each kind that Moses took on the ark" despite knowing that the correct answer is Noah, not Moses. The relative inability to notice these errors raises questions about how people establish and integrate inferences and which conditions improve error detection. To unravel the neural processes underlying inference and error detection in language comprehension, we carried out an fMRI study in which participants read sentences containing true or false statements. The false statements either took the form of more obvious (i.e., clearly false) or subtle (i.e., semantic illusions) inconsistent relations. Participants had to decide if each statement was true or false. Processing semantic illusions relative to true and clearly false sentences significantly engaged the right inferior parietal lobule, suggesting higher demands in establishing coherence. Successful versus unsuccessful error detection revealed a network of regions, including right dorsolateral prefrontal cortex, orbitofrontal, insula/putamen and anterior cingulate cortex. Such activation was significantly correlated with overall response accuracy to the illusions. These results suggest that to detect the semantic conflict, people must inhibit the tendency to draw pragmatic inferences. These findings demonstrate that fronto-parietal areas are involved in inference and inhibition processes necessary for establishing semantic coherence.



## Introduction

As a sentence or narrative unfolds, the listener builds-up an interpretation of the linguistic input based on various sources of information including semantic, syntactic and pragmatic information. Many times, developing such interpretation involves not just understanding what is said, but also inferring what is implicitly stated. People draw inferences from discourse to establish coherence between individual events (Graesser et al., 1994; McKoon and Ratcliff, 1992). For instance, if one is told that "she no longer writes fiction", one may infer that "she once wrote fiction". A clear example of the role of inference in discourse comprehension is the case of cleft sentences. A cleft sentence divides a proposition into two parts, whereby the cleft constituent expresses the focus and the cleft clause expresses a presupposition (Prince, 1978). In it-cleft sentences such as "It was a poem that he read last night", the focused information ("It was a poem") is typically analyzed exhaustively, whereas the non-focused or background information ("that he read last night") is often assumed to be true and taken for granted (Graesser et al., 1994; McKoon and Ratcliff, 1992). It is well known that focused information is detected more quickly (Birch and Garnsey, 1995; Cutler and Fodor, 1979) and is also better remembered (Singer, 1976) than non-focused information, indicating that focus plays an important role in sentence comprehension.

The extreme case of the effect of focus in cleft sentences is the semantic illusion phenomenon, in which the listener fails to notice a semantic anomaly in a sentence. In the Moses illusion, many participants do not immediately detect errors reading the sentence "It was two animals of each kind that Moses took on the ark" despite later showing knowledge that the correct reference is Noah, not Moses (Erickson and Mattson, 1981). The close semantic relationship between the incorrect word (Moses) and the critical word (Noah) is a prerequisite for the illusion to occur (Barton and Sanford, 1993; Ferreira et al., 2002; Park and Reder, 2004; van Oostendorp and de Mul, 1990). However, the sentence focus crucially affects the illusion rate. In the standard illusion, participants direct their attention to the main focus of the sentence that contains true information ("It was two animals of each kind") and miss the incorrect presupposition ("that Moses took on the ark"), resulting in a high illusion rate (Brédart and Modolo, 1988). In contrast, the illusion significantly decreases when the focus shifts to the inconsistent part of the sentence, such as in "It was Moses who took two animals of each kind on the

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ark". Thus, in the standard Moses illusion, people draw a pragmatic inference that the non-focused information is true, processing this given or background information in a semantically shallow manner (Brédart and Docquier, 1989; Brédart and Modolo, 1988; Sanford et al., 2006). To fully and properly process these cleft sentences, readers must compute this pragmatic inference. More specifically, to detect the anomaly in the sentences, people must monitor and inhibit the automatic inference that the given, non-focused information is correct (Sanford and Sturt, 2002; Sturt et al., 2004).

In this fMRI study, we use the Moses illusion to investigate the neural network involved in establishing coherence and detecting errors in sentence processing. We chose the Moses illusion paradigm because it is a very robust phenomenon, easily obtained in the laboratory and a useful tool for exploring the construction of meaning. By comparing conditions under which people fall prey to the illusion and those in which people are able to correctly detect errors we can disentangle distinct sentence comprehension processes. Not noticing the error indicates that people accept the standard implication that the non-focused information is accurate and build-up a coherent representation of the sentence (Sanford and Sturt, 2002). In contrast, the ability to detect errors presumably requires executive control processes, such as conflict monitoring and response inhibition processes (Bottoms et al., 2010; Hoenig and Scheef, 2009). Thus, we apply this paradigm to investigate the neural mechanisms supporting core aspects of sentence comprehension. More specifically, we aim to identify the brain regions associated with drawing inferences to establish coherence, and to explore which areas are recruited when errors are successfully detected.

Patient data and fMRI studies have provided some insights into the brain regions that support the elaboration of inferences in order to derive a coherent message-level interpretation. Neuropsychological studies have shown that right hemisphere lesions are associated with impaired comprehension of discourse that requires the generation of inferences (e.g., Beeman, 1993; Brownell et al., 1986). For instance, in a study in which participants listened to stories that promoted inferences, Beeman (1993) reported that right hemisphere-damaged patients answered less accurately to inference questions than explicit questions compared to controls and also responded more slowly to inference-related than unrelated words in a lexical decision task. Supporting the neuropsychological literature, fMRI studies that compared coherent and incoherent texts have also implicated the right hemisphere in establishing discourse coherence (Kuperberg et al., 2006; Mason and Just, 2004; Xu et al., 2005). Mason and Just (2004) presented participants with two-sentence passages that varied in their degree of causal relatedness. The results showed that the ability to draw elaborative inferences was mediated by two cortical networks, a reasoning system in bilateral dorsolateral prefrontal cortex associated with the generation of inferences, and a right hemisphere language network linked to the integration of inferences in context. In another fMRI study, Kuperberg et al. (2006) have investigated the neural mechanisms underlying discourse comprehension, and particularly those mediating the establishment of inferences across sentences. The authors found a sustained engagement of right inferior parietal cortex and bilateral temporal–prefrontal cortices when participants had to generate and use inferences to build up coherence across sentences. Taken together, these data suggest that making sense of discourse involves an extensive cortical network including right fronto-parietal areas to understand what is implicitly stated. It has been proposed that this network reflects the activation, retrieval and integration of information from semantic memory into incoming discourse structure during the processing of inferences (Kuperberg et al., 2006).

In contrast, successful error detection involves increased monitoring processes, in order to detect that the sentence contains a semantic anomaly that conflicts with world knowledge (Bottoms et al., 2010). Studies have suggested that monitoring response conflict involves anterior cingulate cortex (ACC) activation (Badre and Wagner, 2004; Braver et al., 2001). It has been proposed that the ACC signals the occurrence of conflict in information processing, thereby triggering compensatory adjustments in cognitive control (Botvinick et al., 2004). Critically, in order to answer accurately to the illusions, people must not only detect the conflict in the sentence, but also to inhibit the tendency to respond that the sentence is correct. Imaging studies investigating inhibitory control in the decision-making literature have highlighted the role of right lateral PFC in response inhibition (Aron et al., 2004; Chikazoe et al., 2007; De Neys et al., 2008; Hoenig and Scheef, 2009). However, in the context of sentence comprehension, it is still unclear whether similar regions would be recruited to overcome a dominant response tendency.

We addressed these issues in an fMRI study that used Moses illusion type sentences and a sentence verification task. Sentences in the study differed in the degree to which information was semantically coherent: sentences were either true (i.e., statements containing correct semantic and world knowledge information, e.g., *It was Batman who swore to revenge his parents' death fighting against crime*); clearly false (i.e., statements that clearly violated world knowledge; *It was the hunters who killed Bambi's mother when she was on the beach*); or semantic illusions (i.e., statements containing a semantic error that was difficult to detect; *It was the terrible stepmother who tried to kill Cinderella with a poisoned apple*). Based on previous behavioral studies (Reder and Kusbit, 1991), we hypothesized that verifying sentences containing semantic illusions is more demanding than verifying both true sentences (where conceptual relations are intact) and false sentences (in which the semantic incongruence is easily detected). In semantic illusions, a focus on the cleft constituent of the sentence ("It was the terrible stepmother") and the overlook of the cleft clause ("who tried to kill Cinderella with a poisoned apple") will lead to the incorrect inference that the sentence is true and to the inappropriate integration of the error in sentence comprehension. Such generation and integration of inferences should be associated with increased response in the right hemisphere regions, namely in the inferior parietal cortex, during processing of illusions compared to other types of sentences (Kuperberg et al., 2006). Moreover, within the semantic illusion condition, successfully noticing the error, relative to failing to notice the error, should involve frontal activation associated with executive control (Hoenig and Scheef, 2009; Rodd et al., 2010). In order to answer correctly to the illusions, people must monitor the conflict in the sentence and additionally must inhibit the intuitive but inappropriate response. Thus, we expect ACC activation linked to conflict monitoring (Botvinick et al., 2004) and right lateral PFC activation associated with response inhibition (De Neys et al., 2008) to be particularly relevant during successful detection of illusions.

## Method

### *Participants*

Seventeen right-handed, healthy participants, native speakers of Portuguese (18–25 years old, 16 females) took part in the study. All gave informed written consent to the experimental procedure, which was approved by the local ethics committee.

### *Materials and procedure*

The stimuli consisted of 160 written sentences, half of which were true statements (e.g., *It was Batman who swore to revenge his parents' death fighting against crime*), and half of which were false. Within the false sentences, half were clearly false, i.e., they contained a highly implausible reference (e.g., *It was the hunters who killed Bambi's mother when she was on the beach*), while the other half were semantic illusions, i.e., sentences that contained a plausible but misleading reference (e.g., *It was the terrible stepmother who tried to kill Cinderella with a poisoned apple*). Most semantic illusions were modified from published