WHEN THINGS DO (NOT) REFER: AN FMRI STUDY ON ANAPHORA IN DISCOURSE

By

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To Brian, Dorito, and Gwen, who have now dealt with the writing of two theses.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
aTL	Anterior temporal lobe
BOLD	Blood oxygen level dependent
BVQX	BrainVoyager QX
CI	Construction-Integration
dlPFC	Dorso-lateral prefrontal cortex
dmPFC	Dorso-medial prefrontal cortex
ELAN	Early left anterior negativity
EPI	Echo-planar imaging
ERP	Event-related potential
FFX	Fixed-effects analysis
fMRI	Functional magnetic resonance imaging
FOV	Field of view
GLM	General linear model
HRF	Hemodynamic response function
IFG	Inferior frontal gyrus
IPC	Inferior parietal cortex
ISI	Inter-trial stimulus
LH	Left hemisphere
LIFG	Left inferior frontal gyrus
LMedFG	Left medial frontal gyrus
LMFG	Left middle frontal gyrus
LPreCG	Left precentral gyrus
LSFG	Left superior frontal gyrus

LSTS	Left superior temporal sulcus
MRI	Magnetic resonance imaging
ms	Milliseconds
PCC	Posterior cingulate cortex
PET	Positron emission tomography
pIPFC	Posterior inferior prefrontal cortex
pTL	Posterior temporal lobe
RaTL	Right anterior temporal lobe
RF	Radio frequency
RFX	Random effects analysis
RH	Right hemisphere
RIFG	Right inferior frontal gyrus
RIFS	Right inferior frontal sulcus
RMFG	Right middle frontal gyrus
ROI	Region of interest
RPreCG	Right precentral gyrus
RSTG	Right superior temporal gyrus
RT	Reaction time
s	Seconds
SENSE	Sensitivity encoding; a specific type of imaging technique utilized to reduce scan time
TD	Talairach Daemon
ToM	Theory of mind
TR	Repetition time
UTHSCSA	University of Texas Health Science Center San Antonio
WM	Working memory

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How do we analyze referents in multi-sentence discourses when they do not match? Discourse processing is generally considered a right hemisphere function; however this stance is somewhat controversial, as experiments until now have not elicited consistent results. To determine what areas of the brain speakers activate and thereby gain a better understanding of discourse and quantifier processing, we designed and conducted the following fMRI experiment.

Fourteen neurologically healthy, monolingual speakers of English viewed 128 sets of two-sentence trials (constructed based on the results of 3 offline pretests). Experimental sentences either had matching quantifiers or mismatched ones: Four tires were leaking some air. All four had already been patched last week (plausible); Four tires were leaking some air. All three had already been patched last week (implausible).

The first sentence of each set was presented two words at a time, for 400ms each (200ms blank in between). The first two words of the second sentence (containing the second quantifier) were presented in the same manner; the rest of the second sentence was shown word-by-word for 300ms each (separated by 200 ms blank). Subjects were then cued to judge (by pressing buttons) whether the two sentences were plausible or implausible together.

An analysis of the data seen in the current study does not support the idea that discourse processing is lateralized to the right hemisphere in the brain. No areas of activation were statistically significant in a comparison of the implausible to the plausible trials. However, comparing the plausible to the implausible trials yielded nine significantly activated areas. Activation in the left hemisphere's prefrontal cortex, which has been implicated in inferencing and integration processes (Mason & Just 2004, Kuperberg et al. 2006), in addition to activation seen in the right superior temporal gyrus, support the idea that these areas are involved in the successful integration of semantic relationships (propositions) between the first and second sentences in the plausible but not the implausible trials, as semantic integration in implausible trials is impossible. Further analysis looking at the functional connectivity among these regions will contribute to the understanding of the network that may exist, possibly relating the activations which appear in the present study.

CHAPTER 1
INTRODUCTION

Although many functional magnetic resonance imaging (fMRI) studies have been conducted looking at discourse processing (e.g. Chow et al. 2007; Robertson et al. 2000) and reference processing (e.g. Almor et al. 2007, McMillan et al. 2005), none has specifically studied the interpretation (or misinterpretation) of referents in discourse. Our experiment sought to remedy that deficit. We looked at how participants interpreted quantifiers (number words) in a two sentence discourse, both when the two numbered groups matched and when the groups' numbers did not match. Specifically, we were interested in the effects of implausible quantifier mismatches on patterns of activation in the brain, and whether there were hemispheric asymmetries in resolving this type of reference problem. Because previous research has implicated areas in the right hemisphere (RH) for the processing of discourse, we anticipated activation in the RH if previous hypotheses were sound.

Discourse Processing

When processing sentences in a discourse, the reader or listener creates a mental representation of the people, objects, and relationships mentioned in the discourse. The representation is continually updated and maintained as the reader progresses further along in the discourse, incorporating new participants and events or modifying the representation as it pertains to previously mentioned referents. For example, when readers interpret the sentence 'The kitten and the puppy were adopted from the animal shelter', they create a discourse model in which the two noun phrases, 'the kitten' and 'the puppy', exist as entities. If a following sentence were to begin with a noun phrase 'The kitten…', readers could either assume that the kitten in the previous sentence is being referred to or that a new kitten is being referred to, and

add another “kitten” referent into their discourse model. (If a new sentence were to begin ‘The chameleon…’, readers would be forced to set up a new discourse referent.)

Studies have shown that readers prefer to interpret a second noun phrase as referring to a previously mentioned entity, rather than set up a new discourse referent. McKoon and Ratliff (1992) in particular have demonstrated through behavioral methods that processing and creating new referents is harder than relating new information to entities previously mentioned in the discourse. In other words, it is easier to ascribe new information to something currently being talked about than create an entirely new referent for that new information. Neurolinguistic results have also supported this idea of new referents being hard to process; Kaan, Dallas, and Barkley (2007) elicited a Late Positive Complex when a new referent needed to be set up in their event-related potential (ERP) study of the processing of bare quantifiers in discourse, which they concluded was due to difficulty in updating the participants’ mental models. Psycholinguistic results also support this conclusion. Wijnen and Kaan’s (2006) behavioral and Frazier and colleagues’ (2005) eyetracking results also attest to the difference in processing between creating new referents and applying information directly to a previously mentioned entity; participants preferred a reading of the discourse so that the second quantified entity was a subset of the previously introduced one.

Levels of Representation

Most processing theories so far postulate that readers construct (at least) two levels of representation when interpreting discourse: a propositional representation and a situational model. These two levels of processing reflect the ways in which the discourse can be described. The propositional level reflects what words and ideas are contained within the sentences given. At this level of processing, representations of semantic structure (called propositions) are formed. Anaphora are incorporated into the discourse model at the propositional level, as well,

according to Long, Baynes, and Prat (2005). The second level, the situational level, reflects a more global, abstract view encompassing what the text is actually about – and incorporating general world knowledge. The situational level, then, includes the reader's own interpretation of the events.

Walter Kintsch and Teun A. van Dijk (1978) were some of the first to hypothesize these two levels of processing. Many researchers also assume that it is necessary to also build and maintain coherence at each level (only local coherence for the propositional, and local and global coherence for the situational level). The formation of local coherence involves the reader mapping the new information onto the recent, previously stated context; global coherence involves mapping the new information onto "relevant information presented earlier in the text but that is no longer available in working memory" (O'Brien, Rizzella, Albrecht, and Halleran 1998). Global coherence also involves the incorporation of general world-knowledge.

This distinction between (at least) two levels of discourse processing has gained support from experimental results. Long and Baynes (2002) used an item-priming-in-recognition paradigm and found that propositionalization was largely a left hemisphere (LH) function, whereas situational level effects occurred bilaterally. Long, Baynes, and Prat (2005) further expanded on this result by demonstrating their LH result for propositionalization is due to neither the close proximity of the noun phrases nor the standard noun-verb-noun syntactic structure of the sentences; the result stands even with the presence of an embedded clause interrupting this normal word order. These results lend support to the idea that there are qualitative and quantitative differences in activation between the propositional and situational levels of discourse.

Quantifiers

The current experiment made use of quantifiers to investigate reference processing. Quantifiers are words such as “most”, “nine”, “seventy”, and “some”. For a quantifier to make sense, it needs to specify the quantity of something – namely, a noun phrase. However, depending on context, a noun phrase need not be present in the actual sentence for the meaning to be understood. (If someone were talking about cats and said ‘Most are grotesquely overfed’, a listener would interpret the quantifier ‘most’ as referring to the discourse topic – cats.) When used without an accompanying nound phrase, quantifiers are a type of anaphora in that they refer to a group or entity, usually previously mentioned or in some way related to another discourse referent.

Van Benthem (1986) demonstrated a difference between two main types of quantifiers: first-order quantifiers and higher-order quantifiers. By modeling each type with automatons; he showed that while first-order quantifiers (e.g. “six”, “four”) can be modeled with a simple computing device (a finite state automaton), higher-order quantifiers (e.g. “most”, “few”) needed a more complex automaton that has a WM-like device. McMillan et al. (2005) provides a well-written distinction between the two types; while first-order quantifiers activate one numerical quantity , higher-order quantifiers must activate a numerical quantity and then perform judgments upon that quantity – utilizing resources such as working memory (WM) to do so. First-order quantifiers do not have this additional resource usage.

The present study uses quantifiers to further investigate the functional areas involved in discourse and reference processing. The manipulation of whether the quantifier in the second sentence matched or did not match the quantifier of the first, being the basis for our two conditions, should elicit a qualitatively and possibly quantitatively different result based on the construction of propositional and situational models. In other words, based on the ability to

construct an integrated semantic representation of the sentences, we should see differential activation (either a stronger or weaker signal in the same place or a different location).

CHAPTER 2
BACKGROUND

Discourse Processing and the Right Hemisphere

Most researchers ascribe to a model in which the right hemisphere (RH) functions as the processor for discourse comprehension and pragmatic qualities (e.g. Bookheimer 2002, Robertson et al. 2000, Hoen et al. 2006, Xu et al. 2005). Some, such as Rapp et al. 2004, ascribe some sentence-level processes to the RH as well. While the RH no doubt plays at least a small or supporting role in discourse processing, the data are still inconsistent and have mixed results. Additionally, researchers have tended to overgeneralize their findings; when data was acquired only from a specific region of the brain, concluding that "discourse comprehension was accompanied by more neural activity in the right than the left hemisphere" (Robertson et al. 2000) does not seem to follow.

Patient Studies

One area of investigation that has lead researchers down this RH path is patient studies. Patients with RH lesions tend to show problems with inferencing, revising incorrect interpretations (Ferstl 2007), and maintaining coherence (Mason and Just 2004). However, patient data (while a valuable resource to gain a starting point for investigation) cannot tell us much at this level of language comprehension, for two reasons. First, the extent of most patients' lesions is not confined to one specific area – nor are the lesions readily comparable to each other. Some lesions extend into frontal regions as well. Brain injury patients with frontal lobe damage also exhibit many of the same kind of deficits as RH lesion patients. While the RH and frontal lobes' text comprehension processes are likely not the same, there does not seem to exist an account outside of psycholinguistic models which has reconciled this with neuropsychological proposals (Ferstl 2007).

FMRI and PET

While many neuroimaging studies examining discourse processing find significant activation in the RH, there are many which do not. Task differences and confounded factors take some of the blame for this lack of consistency (Ferstl 2007), but another factor is also a player in the differences seen for discourse processing studies: the neuroimaging method used. Unless care is taken when scanning with fMRI in orbitofrontal and anterior temporal regions (due to the sinus cavities), signal loss can occur. Positron emission tomography (PET) is better at imaging these regions, but it is often more difficult to time-lock stimuli to the acquisition of data. While there are some fMRI experiments that show anterior temporal lobe (aTL) activation (e.g. Ferstl, Rinck, and Von Cramon 2005), others lack this result (e.g. Robertson et al. 2000). Blocked designs, which are seen in some studies in both methodologies (e.g. Robertson et al. 2000), also make it difficult to determine which activation is due to what manipulation. Comparison of activation across studies is further impeded by the regions of interest chosen prior to scanning; in some studies, the aTL was not included as an acquisition area at all (Mason and Just 2004). All of these factors together make it difficult to determine to verify to what extent the RH is involved in discourse and reference processing.

Xu et al. (2005) is of the opinion that this lateralization of activation into one hemisphere or the other is task- or context-driven. They found more bilateral activation at the sentence level and more RH activation at the discourse level, in contrast to Long and Baynes's (2002) results. Xu and colleagues also report finding that the hemispheric response was modulated over the discourse being read, so that there was more LH activation at the beginning of the discourse (as propositional structures were being set up) and more RH activation near the end and at the conclusion of the discourse (possibly representing the formation of a globally coherent structure). Xu and colleagues interpret this increased RH activation as a representation of a

globally coherent structure; however, another analysis is possible: the RH activation increases as more and more propositions enter the discourse, taxing executive resources. This result could then be interpreted as representing increased working memory or computational load.

Bilateral activation of the anterior temporal lobes (aTL), as well as left-dominant activation of the superior and inferior frontal regions and inferior parietal areas has also been observed (Mazoyer et al. 1993). Mazoyer and colleagues conducted a PET study comparing a rest baseline with conditions in which participants were presented with (French) word lists, stories in a foreign language, stories in French, stories containing French pseudowords, stories with semantically anomalous content words, and stories in French. In their conclusions, they implicate their anterior temporal lobe (aTL) activation to an involvement in syntactic processing, as they saw this activation even in pseudoword stories. Ferstl and Von Cramon (2001) also observed bilateral aTL activation, and additional areas of activation in the posterior temporal sulcus (pTL) and left-dominant, bilateral involvement of the IFG and post inferior prefrontal cortex (pIPFC) in their comparison of two short texts versus a non-word baseline.

When compared with a non-language baseline, activation across neuroimaging studies for discourse processing seems to focus on the left superior temporal sulcus (LSTS) and the pars opercularis and/or triangularis of the left IFG. Ferstl (2007) adds a caveat in her review of these discourse processing studies, in that none of the activations mentioned is “specific to contextual language comprehension,” being present even in the comparison of a resting state to an attention task (Binder, Frost, Hammeke et al. 1999). Ergo, we cannot conclude that activation in the LIFG and LSTS areas result specifically from processing discourse, though they may be functionally or anatomically linked.

Certain areas of the brain have been implicated in each posited level of discourse processing. However, the story remains unclear as to which areas of the brain are related to each level of processing; overlap abounds. Ferstl and von Cramon's (2001) study examining local coherence (propositional) processes also found activation they believe is related to situational model updating. The previously mentioned study by Mazoyer et al. found activation to be significant only in the narrative condition for the dorso-medial prefrontal cortex (dmPFC), whereas activation in the aTLs was present for both the sentence and story condition. They ultimately conclude that the aTLs play a role in semantic encoding – thereby linking these areas to the propositional level of a model of discourse comprehension. Long and Baynes (2002), however, utilized a hemi-field priming task to show evidence for LH effects of propositional structure. They also found bilateral hemispheric effects for processing at the situational level.

Other areas have been implicated in the situational level of discourse processing. Ferstl (2007) also discussed results implicating the posterior cingulate cortex (PCC) in situational modeling. Based on results from Ferstl and Von Cramon (2002) and Maguire et al. (1999), which found activation in the PCC, she and the other authors concluded the PCC was involved in the integration of novel information with prior context or general world-knowledge.

Another important area of activation is the prefrontal cortex. The dorso-medial prefrontal cortex (dmPFC – BA 8, 9, and 10) activation found in several discourse processing studies (e.g. Mazoyer et al. 1993, Ferstl and Von Cramon 2001) does not have a clear justification as of yet. Ferstl (2007) discusses two possible explanations: theory of mind (ToM) processes or general inferencing processes. Theory of mind refers to the ability to recognize that other people's actions are related to their beliefs and mental states. Based on the results of another study (Ferstl and von Cramon 2002), and the demonstrated result of the dmPFC being more active for

coherent as opposed to incoherent trials, Ferstl (2007) concludes activation in this region is due to general inferencing processes. The dorso-lateral prefrontal cortex (dlPFC) has also been implicated in inferencing processes; or more specifically, in the generation of inferences (Mason and Just 2004).

Inferencing and Integration

Events in a discourse are often not explicitly connected to one another, necessitating that the hearer or reader generate inferences to determine the relationship between the two (or more) events for comprehension. For example, in a discourse such as *I became angry with my cat. The kitchen counter had paw prints on it*, readers must infer that the cat jumped on the counter, that this is the reason the speaker is angry with her, and then integrate those inferences into their discourse model – explaining the relationship between the two sentences. The construction-integration (CI) model of text comprehension (Kintsch 1988) reflects these processes.

As explained by the CI model, readers generate many possible inferences, and then through an integration process select the inferences that relate most to the text-base (what has been stated explicitly). For the example discourse given above, alternative inferences that might also be made that an animal had jumped on the counter, or that the cat failed to clean up the paw prints. These are ultimately rejected because the inference above (that the cat jumped on the counter) is more directly related to the discourse, and ultimately makes more sense. The resulting successful discourse model, then, reflects both the propositions generated from the discourse and the propositions of the successfully integrated inference. Some researchers have come to the conclusion that the RH is involved in inferencing processes as a part of its supposed dominance for discourse processing.

Robertson and colleagues (2000) looked at inferencing processes, which they call “mapping”. They ultimately found two areas of activation for more coherent sentence blocks: the

right inferior frontal sulcus (RIFS) and the right inferior frontal gyrus (RIFG). However, Robertson et al. did not include most of the temporal lobe in their analysis (supposedly to avoid susceptibility artifact). As noted above, this can be a problem with fMRI data acquisition; however, we cannot draw conclusions based on a lack of finding for the temporal lobe in this study. Robertson and colleagues conclude that, based on previous results that implicate the area in allocation of internal attention, this sub-process must be involved in mapping or inferencing processes. Since parts of the temporal lobe were not included in the comparison, they may be involved in this process as well.

As mentioned previously, Ferstl and von Cramon (2001) were interested in investigating local coherence processes, without global text factors or task effects. Using event-related fMRI, they conducted an experiment with two-sentence trials in which they manipulated coherence and cohesiveness (as measured by the insertion of a conjunction or related pronoun). Their participants were told to respond whether the sentences in a trial were pragmatically related to each other, necessitating the generation of inferences to link the two sentences together (for example, *The lights have been on since last night. The car doesn't start*). Ferstl and von Cramon could not, however, replicate the results of Robertson et al.'s study, leading to the continued murky role of the right hemisphere in inferencing processes.

Mason and Just (2004) conducted an fMRI experiment examining causal-related inferencing. According to previous work, an intermediately-related sentence pair was better recalled than either a highly- or distantly-related pair; the theory proposed was that the increase in recall was due to readers having generated a causal inference between the two sentences, which in turn might have increased the number of possible retrieval cues for better recall later on in the task. Mason and Just saw differential activation in what they define as the "RH-language

areas" (including the inferior frontal, inferior parietal, and temporal gyri) for the intermediate versus the highly- and distantly-related pairs. The RH activation seen for this intermediate condition is equal to the LH areas; in the other two conditions, LH activation was greater. Mason and Just use this data as support for Kintsch's construction-integration model. They interpret the RH activation as involved in integration processes, after the dlPFC has been involved in the generation of the inferences. They interpret the LH activation as due to the construction of propositional representations, which they say would likely remain constant across all conditions. Their RH temporal finding is intriguing, as it shows a dramatic increase in activation for the intermediately-related condition, but they conflate the superior and middle gyri without giving specific localization information. They ultimately conclude that the bilateral dlPFC is involved in the generation of an inference, and the RH areas then integrate the successfully generated inference into the reader's discourse model.

Coreference

Almor et al. (2007) examined another area of processing relevant to the current study: anaphora processing and coreference. These researchers were primarily interested in the repeated name penalty (in which repeated use of a name instead of a pronoun increases processing time). Because pronouns are often ambiguous, comprehenders' preference for them over precise, repeated names may seem paradoxical at first. However, when one ascribes to the view that a name causes an automatic generation of a new discourse referent (which as described above, is more difficult to process than relating new information to a previous referent), the preference for pronouns is clearer – if they do not cause the generation of a new referent but instead immediately relate and integrate information into preexisting referents. In this way, pronouns would reduce WM load. Hypothesizing that a repeated name would activate areas related to WM and integration processes, they expected to see activation in the temporal and parietal lobes for a

contrast between their repeated name and pronoun conditions. They used three-sentence trials, with either a repeated name or a pronoun appearing in the second and third sentences. No areas of the brain were found to be more accurate in the pronoun > repeated name condition. Conversely, the repeated name condition led to more activation in the superior parietal lobule and precuneus, left fusiform gyrus and left middle and inferior temporal gyri. Almor and colleagues interpret these results as evidence for generation of new referents for repeated names and for increased integration effects when a newly created referent is analogous to a previously created discourse referent and must be integrated into the discourse model.

Present Study's Contributions

As previously mentioned, this experiment was conducted with the aim of looking at brain areas involved in reference problems in discourse, and whether there were hemispheric asymmetries in the activation seen. The limitations of the literature, discussed above, stem from inconsistencies as to task, imaging methods, and confounded materials; additionally, this single aspect of discourse processing has not been solely investigated before. Many of the studies presented so far have had lexical confounds in their materials, which precluded their use in the current study. For example, in Ferstl and von Cramon's (2001) study, one of their stimuli was *The lights have been on since last night. The car doesn't start.* While this does require that the reader generate an inference that the lights refer to the headlights of the car (and investigates the inferencing sub-component process of discourse) , the introduction of another noun phrase (or a repeated noun, as shown in Almor et al.'s study) and the creation of another referent in the discourse would confound our reference investigation. By utilizing quantifiers, which are able to be used without an accompanying noun (see above), we can avoid this effect. Hence, a set of materials was designed with several factors in mind, based on the results of three offline pretests. These are detailed in the next chapter.

Predictions

In accordance with previous studies on anomalous referent processing and new referent creation, we expected there to be significant activation in the superior and inferior frontal gyri, as those areas have been implicated in inferencing, semantic integration and conflict (Ferstl & Von Cramon 2001). We expected larger activations in general for the right hemisphere (as compared to the LH), if the right hemisphere actually does play an increased role in constructing discourse models. Additionally, we expected activation in the median frontal lobe of the left hemisphere because of its involvement in plausibility evaluations (Stowe et al. 2004). We also expected to find activation in the thalamus and anterior cingulate if their activation, as McMillan et al. (2005) state, does pertain to selective attention. As stated above, Robertson et al. (2000) found significant activation in the right prefrontal cortex for a more coherent version of discourse (utilizing definite articles vs. indefinite articles). If the quantifiers we used are interpreted similarly to definite articles, we can expect activation there as well. In the current study, participants had to relate the first quantity to the second for the plausibility task – which might lead us to expect some activation relating to working memory (WM) for both conditions. We would not see a differential activation, however, because this has to be done for all trials. Activation in the RH's inferior parietal cortex (IPC), which has been implicated in magnitude comparison (McMillan et al. 2005, Cohen et al. 2000), therefore would not be differentially activated for one condition over another, as this process is required of all conditions for the task the participants had to perform.

CHAPTER 3
METHODS

Participants

Eighteen monolingual speakers of English (9 female; aged 18-26, mean age 22) participated in this study. All were right-handed and had normal or corrected-to-normal vision. Based on responses from health and education questionnaires, none had any history of brain trauma, language or learning disability, reading abnormality, substance abuse, or indicated to be on any psychiatric drugs. All participants were compensated for their time and participated according to University of Florida Institutional Review Board procedure; most were University of Florida students. None of these participants participated in any pretest of the materials.

Two of the eighteen participants were omitted from the analysis due to equipment malfunction (a female, 18, and a male, 25). Another two (a female, 18, and a male, 24) were omitted on the basis of their accuracy scores (which fell significantly outside the rest of the data). Hence, the data analysis reported below includes data from a total of 14 participants.

Materials

The materials went through three different pretests, which were primarily directed toward two goals: confirming the experimenters' plausibility judgments and removing any significant differences in reaction time (RT) and accuracy between the conditions. The materials were presented in the same way as the current study (machine-paced, not self-paced), because we were interested in replicating conditions in the MRI scanner. Using self-paced reading would have varied the rate at which participants could have processed the sentences (possibly resulting in a mismatch between stimuli presentation and image acquisition) and elicited increased, prolonged activation of the motor cortex. Additionally, we did not want to present entire sentences at a

time; doing so would not allow us to know which words the participants are viewing at what time, and could potentially lead to eye movement artifacts.

Keeping these ideas in mind, sentence pairs were created. Each sentence began with a quantifier. The total length of a trial was either 13 or 14 words (two of the distractor conditions had one fewer word than the other conditions). The first sentence in a pair always had six words, which were divided up into pairs for presentation. The second sentence presented the quantifier phrase (e.g. *All six*) at once, and then six more words, one per frame. No noun accompanied this second quantifier. Since we do not introduce another noun phrase (modified by the quantifier) in the second sentence, lexical confounds by the introduction of such a noun are avoided. Another discourse referent is not automatically created, as readers prefer as subset interpretation (as discussed above).

Participants viewed 128 two-sentence trials in total. Sixty-four were experimental items in which the number in the second sentence either matched or did not match the number of the first. Each experimental trial created had an implausible and a plausible variation. The experimental materials were Latin-squared: two lists were ultimately created by counter-balancing the conditions across the lists. Each participant saw only one list and therefore one variation of each trial: 32 items for each of the two conditions.

Distractor items composed the remainder of the sets. There were four kinds of distractor items. Twenty-four of the sixty-four distractor sets were constructed to allow for a plausible quantifier mismatch, thereby reducing the probability that participants would base their judgment on the second quantifier alone before waiting for possible disambiguation with a restrictive (that) clause. For example, in the sentence “Four roofs were repaired this week. All eight that were fixed previously still leak,” the participant must wait until the presentation of “that” to

understand that this sentence does not refer to a subset of the previously mentioned roofs, and therefore arrive at the correct conclusion. These twenty-four comprised the first distractor type. Eight of the distractors (the second type) had the same number in both sentences, but ended implausibly. Thirty-two distractor sets used other quantifiers (all, few, etc.), with an equal amount ending plausibly and implausibly (types three and four). Table 3-1 illustrates each condition and distractor type. Experimental items and distractors were pseudo-randomized so that no more than two trials of the same condition followed each other. The total set of 128 items was split into five blocks of 25 or 26 trials, each block beginning with a distractor item. See Figure 3-1 for a sample block; the colored vertical bars represent the stimuli, as encoded on the righthand legend of the figure.

Procedure

The protocol was first created in E-Prime, Version 1.1.4, produced by Psychology Software Tools Inc. Eloquence presentation software, created by the Invivo Corporation, was used to control the presentation of the protocol and collection of the behavioral responses. Participants were first shown a brief demo of the task they would be performing on a laptop computer, and the entire scanning procedure was explained to them. Once participants were placed inside the scanner, they were shown a practice block of four trials during the anatomical scan to allow them to become familiar with the presentation rate and response procedure. They were instructed to minimize movement and focus their gaze on a fixation cross when not actively reading or responding.

The sentences were presented in white on a black background and were viewable on a mirror positioned above the participant's head which reflected a computer monitor behind him or her. At the beginning of each block, a fixation cross (+) was presented for 8000ms. Seven hundred milliseconds before the first trial began, the color of the cross changed from white to red

to signal to the participant that a sentence was about to be presented. The first sentence was then presented, two words per frame, for 400 milliseconds per frame. The first two words of the second sentence (or one word, in the case of the third and fourth type of distractors) and every word thereafter was presented for 300ms. Every presentation of text was followed by a 200ms gap. The critical word here is the fifth frame of the trial; at this point, it is clear that there is no further modifier. Each trial had ten frames, as indicated by '|'s in Table 1.

Participants were cued at the end of each pair by the 2000ms presentation of a string of three question marks ('???'), signaling that they needed to judge whether the sequence of two sentences together were plausible or implausible. A plausible response was indicated with the right index finger and an implausible response was indicated with the right middle finger, using an MR-compatible button box. This kept the participant actively paying attention through the end of the sentence, because nearly a fifth of the sentences became plausible after the quantifier phrase; in order to judge correctly, attention had to be given.

There was an inter-stimulus interval (ISI) of between seven and eleven seconds, varying in half-second increments. During the ISI, the fixation cross was shown; just as at the beginning of each block, before each trial began, the cross became red. The ISI was jittered to allow for a varied sampling rate throughout the hemodynamic response to the critical word. Each experimental block lasted approximately seven and a half minutes. After the five blocks requiring the reading and judgment task, participants were asked to relax and close their eyes while a final scan was performed.

MRI Data Acquisition

The scanning was conducted on a 3 Tesla Philips Whole-Body System located at the McKnight Brain Institute at the University of Florida. Participants wore earplugs and MR-safe headphones to reduce noise. Anatomical T_1-weighted TFE SENSE structural images were

obtained (TR=8.04ms, 144 axial slices, FOV=240 × 240 × 144mm, 256s duration), then functional images were acquired.

The functional data were obtained using a T2-weighted echo-planar imaging (EPI) pulse sequence (TR=2000ms, TE=30ms, flip angle= 80º, matrix=3.75^3 mm, 36 axial slices, ascending interleaved acquisition parallel to the AC-PC plane) sensitive to blood oxygen level dependent (BOLD) contrast. Two hundred and thirty-one volumes were acquired over each of the five experimental blocks. At the beginning of each block, two disdaq (dummy RF excitation) pulse sequences were conducted to allow for more stability in the signal acquired. The imaging computer then produced an RF pulse when the acquisition of data began, time-locked with the presentation of the stimuli.

Data Analysis

BrainVoyager QX software (BVQX), created by Brain Innovation, Inc., was used in the analysis of the imaging data. Structural and functional images were first coregistered and then converted to standardized Talairach space. Functional images were next preprocessed to reduce artifacts. The preprocessing included: (i) slice scan time correction, (ii) motion correction, (iii) linear trend removal, (iv) spatial smoothing (4 mm full width at half maximum Gaussian kernel applied to reduce differences in intersubject localization), and temporal smoothing (high-pass, 3*data points).

Significant activity was mapped by using a General Linear Model (GLM) with fixed effects (FFX). In a fixed effects analysis, the degrees of freedom relate to the number of voxels, as opposed to a random effects analysis (RFX) in which the degrees of freedom are related to the number of participants. Hemodynamic response functions were modeled to start at the beginning of each trial, with one function per trial; this provided the analysis a standard activation to compare the actual activation to.

The critical cluster size threshold was set to 128, meaning that an activation area had to consist of at least 128 significant voxels to be reported. Clusters that were significantly activated in this analysis then had their coordinate information exported. Talairach Daemon (TD) software, created by Jack Lancaster and Peter Fox at the Research Imaging Center of the University of Texas Health Science Center San Antonio (UTHSCSA), was used to identify regions of interest (ROIs), based on the nearest gray matter. These ROIs were confirmed in the Talairach atlas available in the Liu lab. ROI GLMs were then conducted for each cluster to determine the specific degree of activation for each.

Table 3-1. Example of stimuli used. "|" indicates the division of frames, as presented to the participant. Critical words in experimental items are underlined.

Condition	Stimulus
Plausible (32)	Five ships | were in | the port. | All five | had | just | left | on | their | voyage.
Implausible (32)	Five ships | were in | the port. | All *three | had | just | left | on | their | voyage.
Distractor 1 (24)	Eight girls | were on | the squad. | All five | that | competed | last | year | had | graduated.
Distractor 2 (8)	Eight students | have very | good grades. | All eight | are | failing | all | of | their | classes.
Distractor 3 (16)	Few lectures | have sparked | my interest. | Most | were | so | boring | that | I | slept.
Distractor 4 (16)	Some tenants | have just | moved in. | All | have | lived | here | for | many | years.

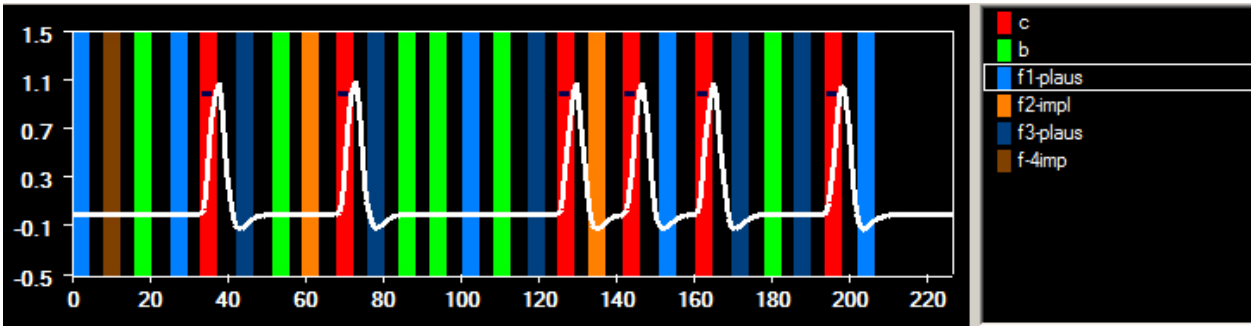

Figure 3-1. The GLM model used. The conditions are color-coded according to the legend on the right. The white spikes are the HRF response modeled for that condition (implausible ("c"), in this case); this was done for each condition, so that each had an HRF response modeled. The numbers at the bottom represent the volume number, and the numbers on the left axis represent the % of BOLD signal change (such that 1.0 = 100%).

CHAPTER 4
RESULTS

Behavioral Data

The behavioral data was analyzed using SAS version 9.1 (Statistical Analysis System). The mean of the reaction times (RTs) for all responses was calculated first, and outliers more than two and a half standard deviations from the mean were replaced with the value of two and a half standard deviations from the mean. A repeated measures ANOVA was conducted with list as a between-subjects factor and condition as a within-subjects factor. Only the List factor approached significance [$F(1,12) = 5.28$; $p = 0.02$]. The main effect of condition was insignificant [$F(1,12) = 0.33$; $p > 0.5$], as was the interaction between condition and list [$F(1,12) = 0.5$; $p = 0.49$]. Table 4-1 shows the means and standard deviations for both the RT and accuracy data. The average accuracy for all of the subjects for the all of conditions was 87.6%; the average accuracy for the critical conditions (overall) was 92.7%. A repeated measures ANOVA was conducted for accuracy within the two experimental conditions, and found there was no significant difference in accuracy levels between the two [$F(1,13) = 3.18$; $p > 0.9$].

Imaging Data

A General Linear Model was set up, and the contrast between the implausible and plausible condition was first examined; however, no clusters were significantly activated at either a corrected (q(FDR)) or an uncorrected p value of 0.05. When the opposite contrast was scrutinized (plausible vs. implausible), nine clusters showed significant activation. They are listed in Table 4-3, and visualized in Figures 4-1 and 4-2.

When activation is seen in the RH for this experiment, it is usually bilateral in nature. Figures 4-6 and 4-9 (right and left claustrum), 4-5 and 4-10 (right and left middle frontal gyrus), and 4-4 and 4-11 (right and left precentral gyrus) are the bilateral activations found for this

experiment. The sole RH activation seen that was not bilateral in nature was the small but significant (384 voxels; p = 0.000000) activation of the right superior temporal gyrus (RSTG).

Overall for the plausible > implausible contrast, activation is observed more in the LH than the RH (5417 voxels in the LH vs. 2324 voxels in the RH). Effectively, 70% of the activation seen is in the LH. The bilateral middle frontal gyrus activation is an order of magnitude greater in the LH than the RH (4254 vs. 439 voxels). The RPreCG and RClaustrum activations are both somewhat larger than their LH homologues, but overall activation is more left-lateralized.

In the LPreCG, where we might expect activation in general (due to motor response), we find stronger activation for the plausible trials than the implausible trials (see Figure 4-11). While the activation levels for both conditions are the same at the beginning of the stimulus presentation, by the end of the presentation and for 12 seconds afterward they remain more negative for the implausible condition versus the plausible condition. For the plausible condition, activation remains significantly more positive (vs. the implausible) in the 8-12sec (4-6 scan) and in the 18-20sec (9-10 scan) ranges, the first corresponding to the hemodynamic response we could expect to see at the presentation of the second referent and the second range approximately occurring for the response seen for the judgment task.

Prefrontal cortex activation is also seen for the plausible > implausible contrast – in the left superior frontal gyrus (L SFG - BA 6), the left medial frontal gyrus (LMedFG - BA 6), the right middle frontal gyrus (R MFG – BA 9), and the left middle frontal gyrus (LMFG - BA 9).

Table 4-1. Analysis of behavioral data, including RT, Accuracy, and standard deviations for each condition.

Condition	Mean RT	St. Dev.	Mean Accuracy	St. Dev.
Plausible	1071ms	605ms	95.3%	3.4%
Implausible	969ms	637ms	90.2%	10.3%

Table 4-2. ROI FFX GLM Analyses, showing degrees of freedom, mean and standard deviations of activation, t value, and significance level.

ROI	df	Mean	Standard error	t value	p value
Overall	16169	10.031	2.38	4.216	0.000025

Cluster	df	Mean	Standard error	t value	p value
R STG	16169	10.217	1.956	5.223	0.000000
R PreCG	16169	9.217	1.861	4.953	0.000001
R MFG	16169	9.501	1.967	4.83	0.000001
R Claustrum	16169	10.327	1.861	5.502	0.000000
L SFG	16169	11.934	2.727	4.376	0.000012
L MedFG	16169	9.43	2.173	4.34	0.000014
L Claustrum	16169	10.903	2.312	4.716	0.000002
L MFG	16169	14.648	2.683	5.46	0.000000
L PreCG	16169	10.031	2.38	4.216	0.000025

Table 4-3. Activated clusters at q(FDR) = 0.05; cluster threshold size = 128. The second through fourth columns refer to the coordinates (in Talairach space) of the center of activation for each cluster.

Cluster	X coor	Y coor	Z coor	Hemisphere	Lobe	Anatomical location	Brodmann's Area	Extent (in voxels)
1	59	-15	-3.2	Right Cerebrum	Temporal Lobe	Superior Temporal Gyrus	Brodmann area 21	384
2	57	4	34	Right Cerebrum	Frontal Lobe	Precentral Gyrus	Brodmann area 6	486
3	39	28	31	Right Cerebrum	Frontal Lobe	Middle Frontal Gyrus	Brodmann area 9	439
4	28	14	11	Right Cerebrum	Sub-lobar	Claustrum	*	1015
5	0.74	14	54	Left Cerebrum	Frontal Lobe	Superior Frontal Gyrus	Brodmann area 6	516
6	-5.5	0.74	61	Left Cerebrum	Frontal Lobe	Medial Frontal Gyrus	Broadmann area 6	190
7	-28	16	11	Left Cerebrum	Sub-lobar	Claustrum	*	216
8	-44	16	31	Left Cerebrum	Frontal Lobe	Middle Frontal Gyrus	Brodmann area 9	4254
9	-44	-5.8	45	Left Cerebrum	Frontal Lobe	Precentral Gyrus	Brodmann area 6	241
								7741 total

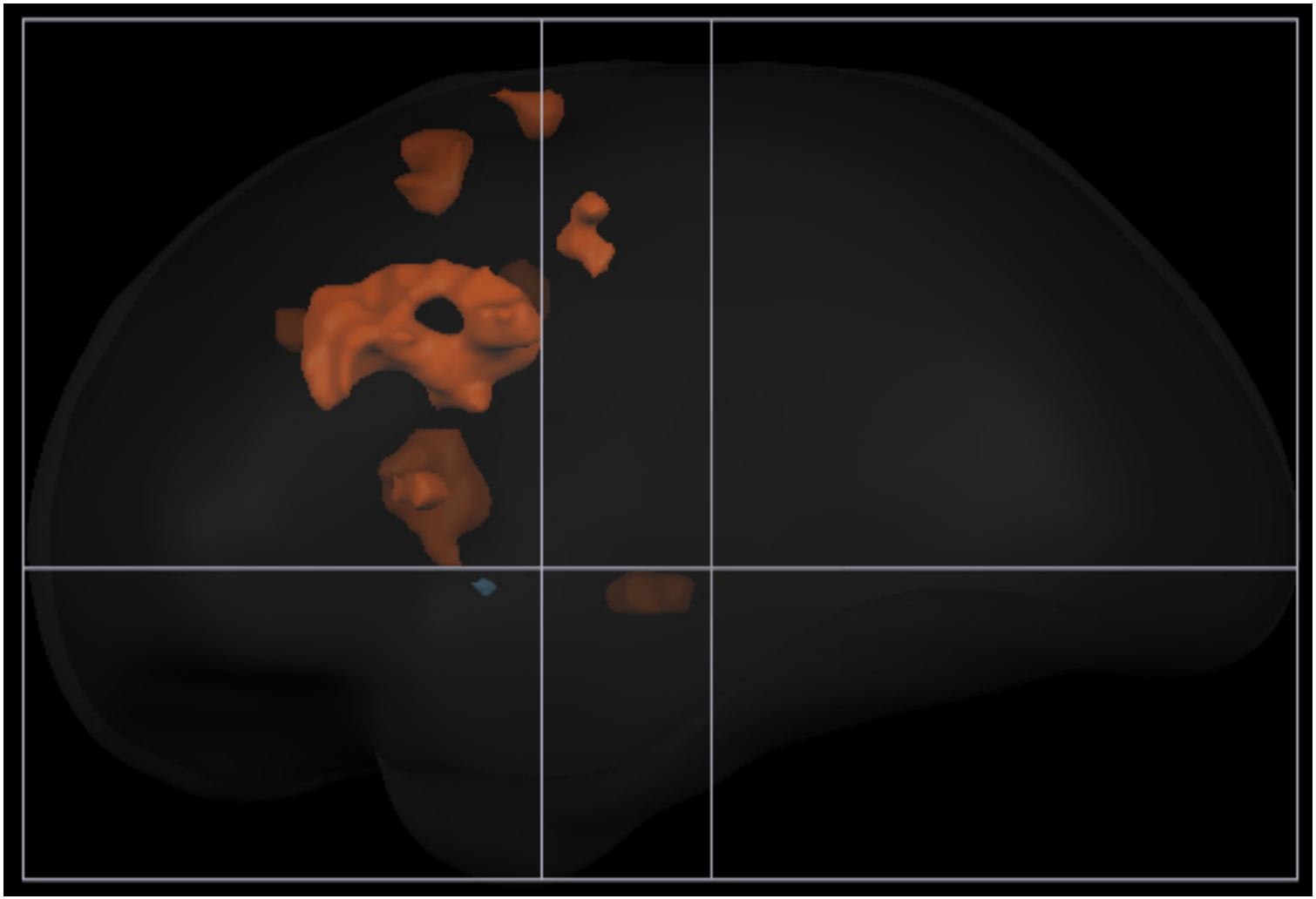

Figure 4-1. The significant areas of activation (in orange and blue) in a glass brain; view of the left hemisphere.

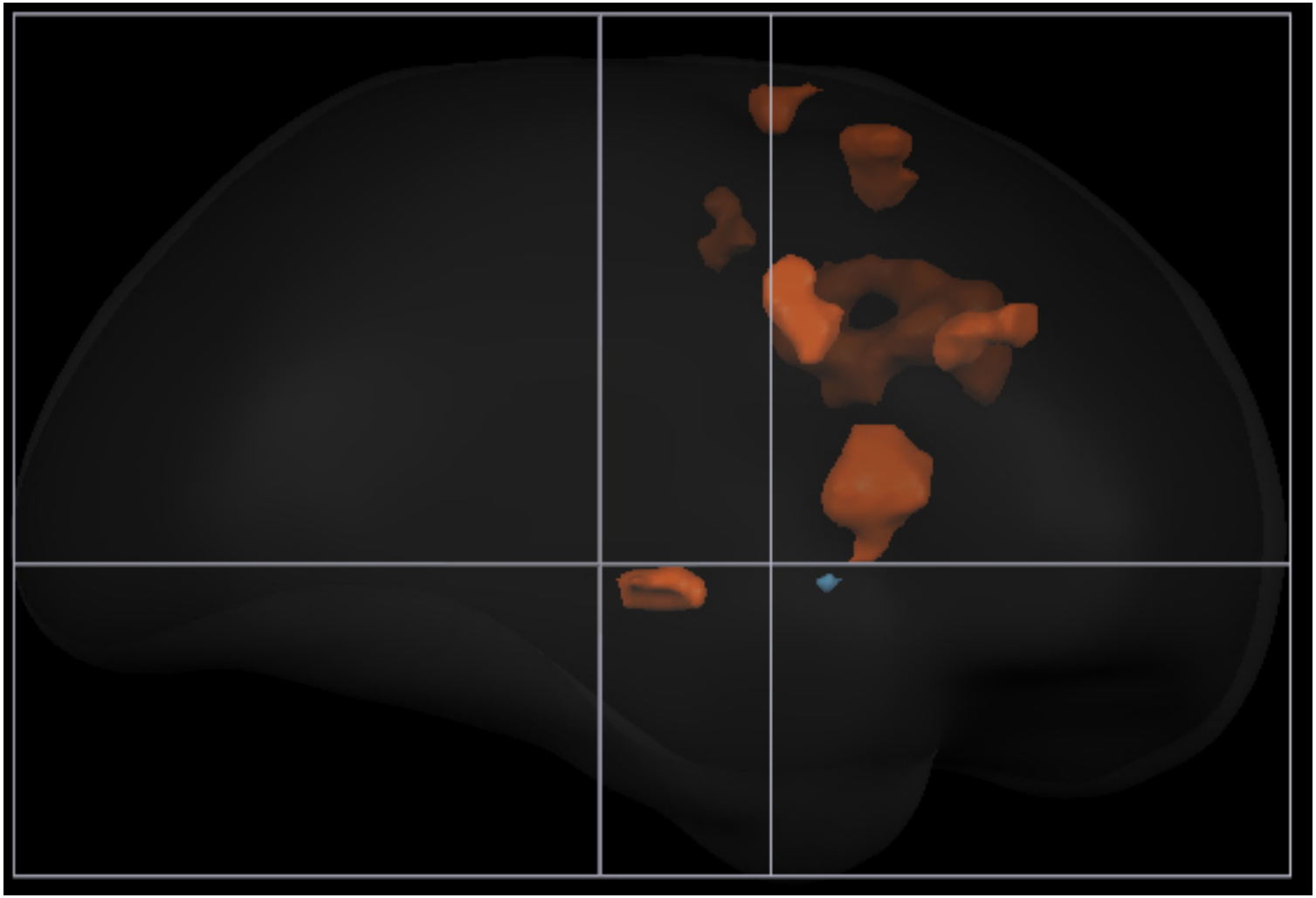

Figure 4-2. The significant areas of activation (in orange and blue) in a glass brain; view of the right hemisphere.

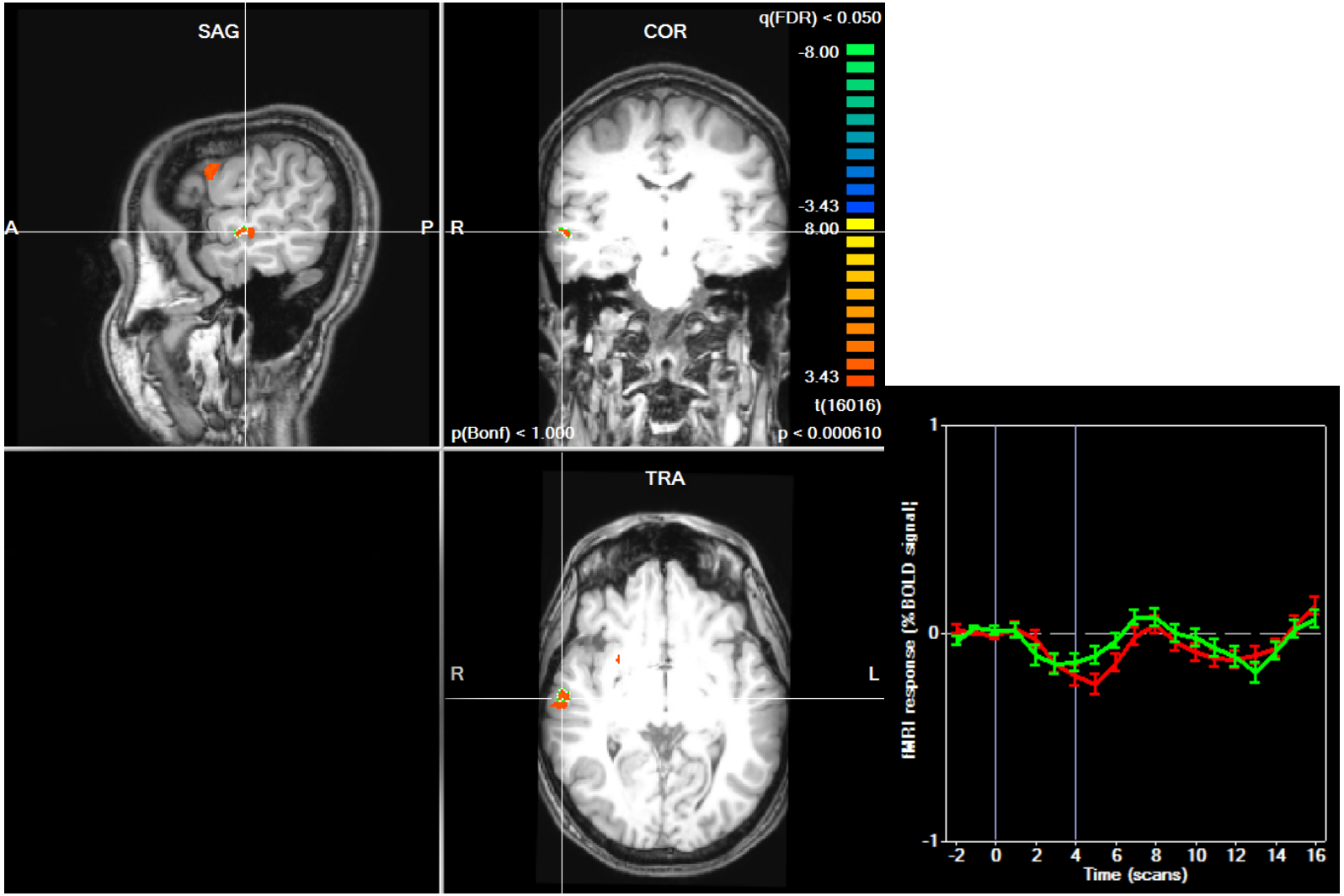

Figure 4-3. The significant activation in the superior temporal gyrus of the right hemisphere (RSTG), along with the event-related averaging plot of the same region. The green line signifies the time course of activation for the plausible condition, and the red the implausible.

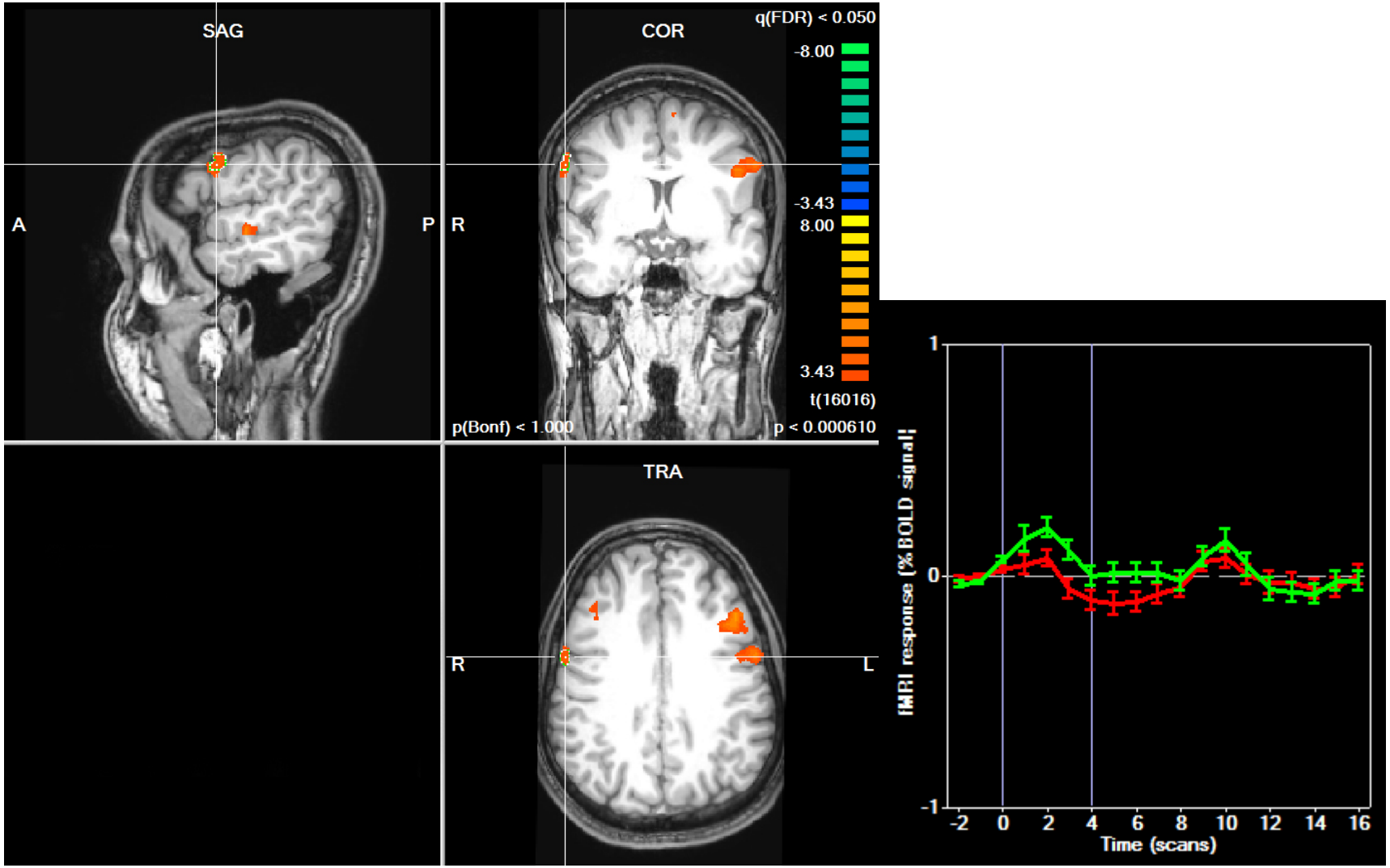

Figure 4-4. The significant activation in the precentral gyrus of the right hemisphere (RPreCG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

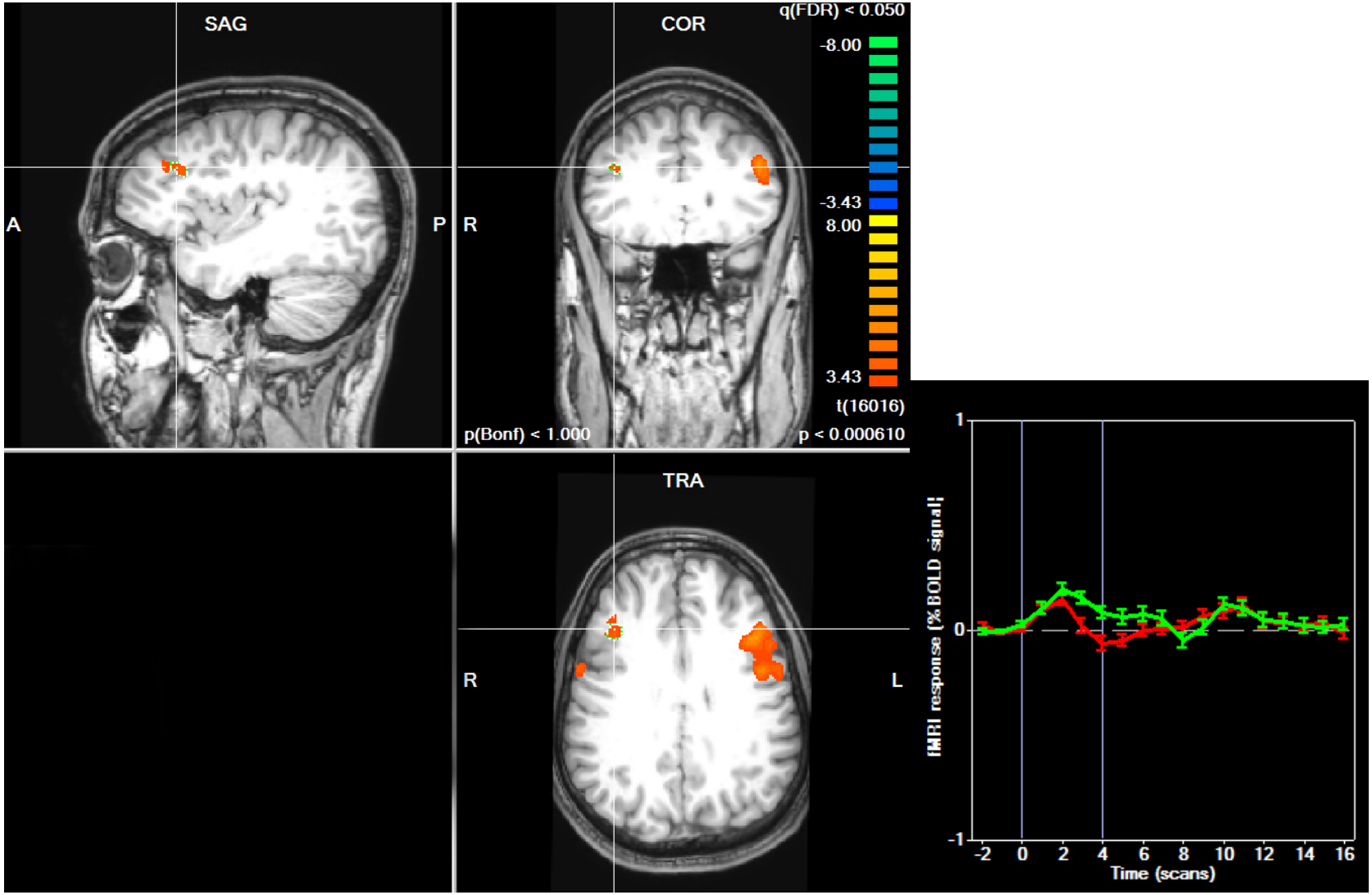

Figure 4-5. The significant activation in the right middle frontal gyrus (RMFG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

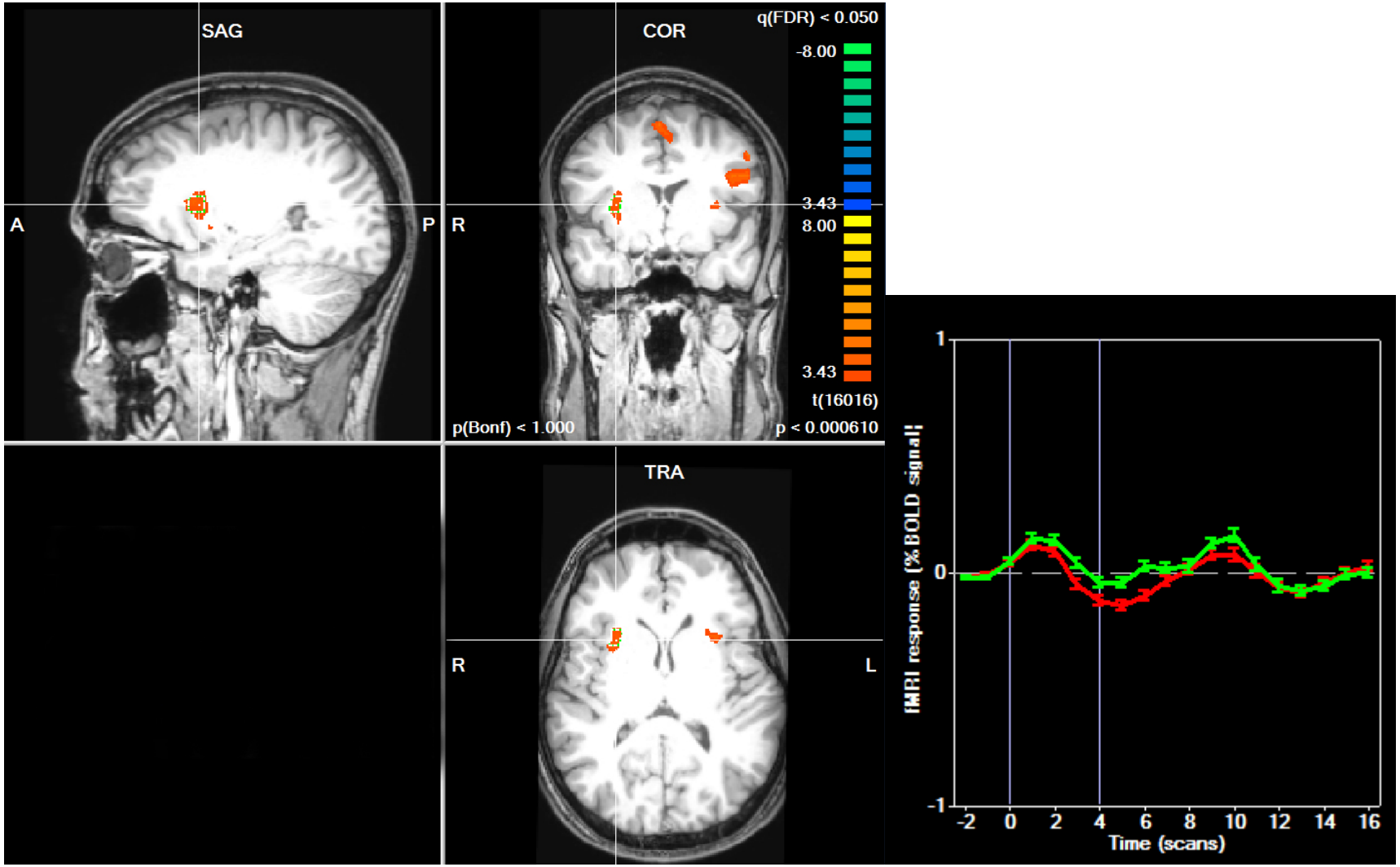

Figure 4-6. The significant activation in the right claustrum, along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

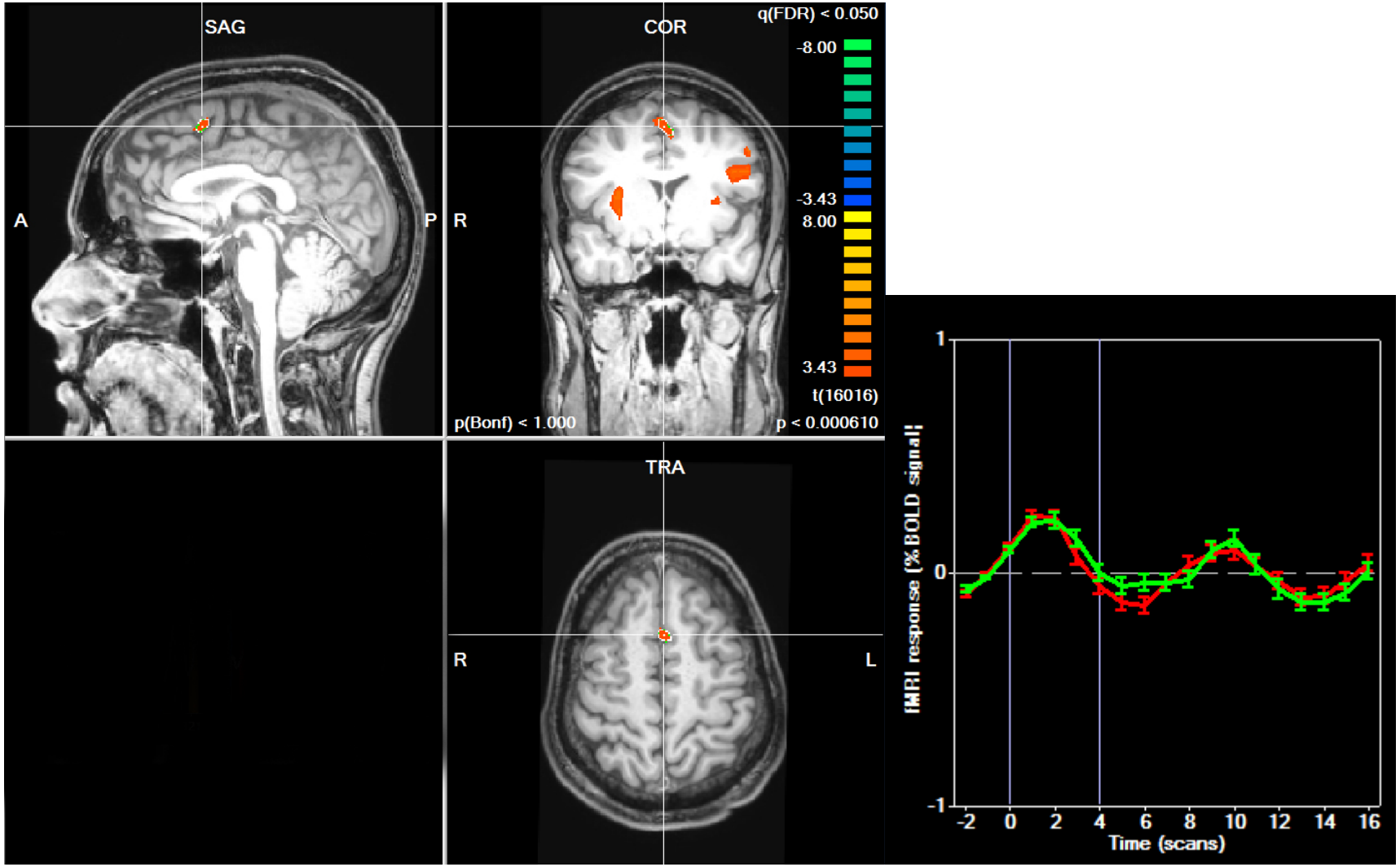

Figure 4-7. The significant activation in the left superior frontal gyrus (LSFG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

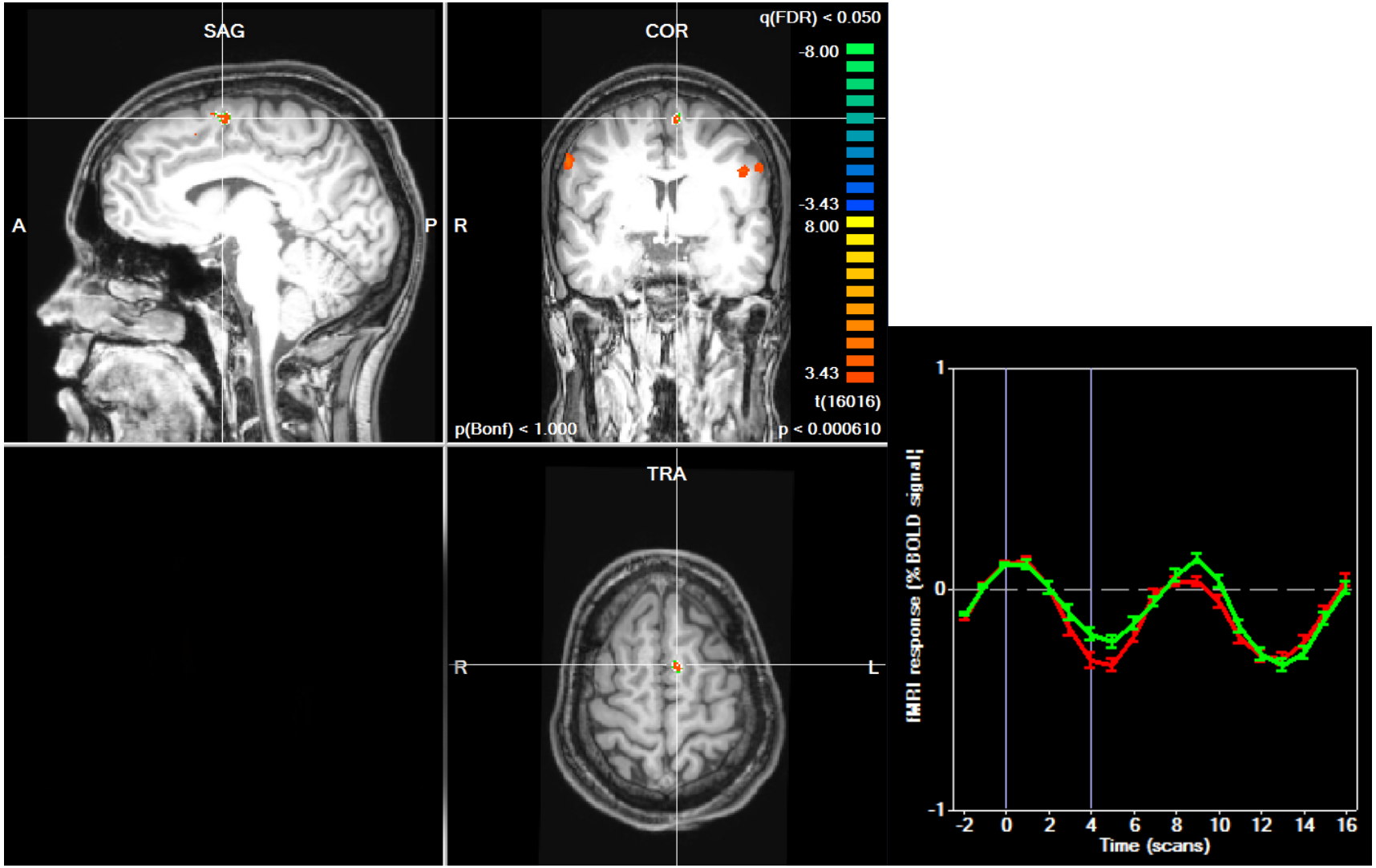

Figure 4-8. The significant activation in the left medial frontal gyrus (LMedFG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

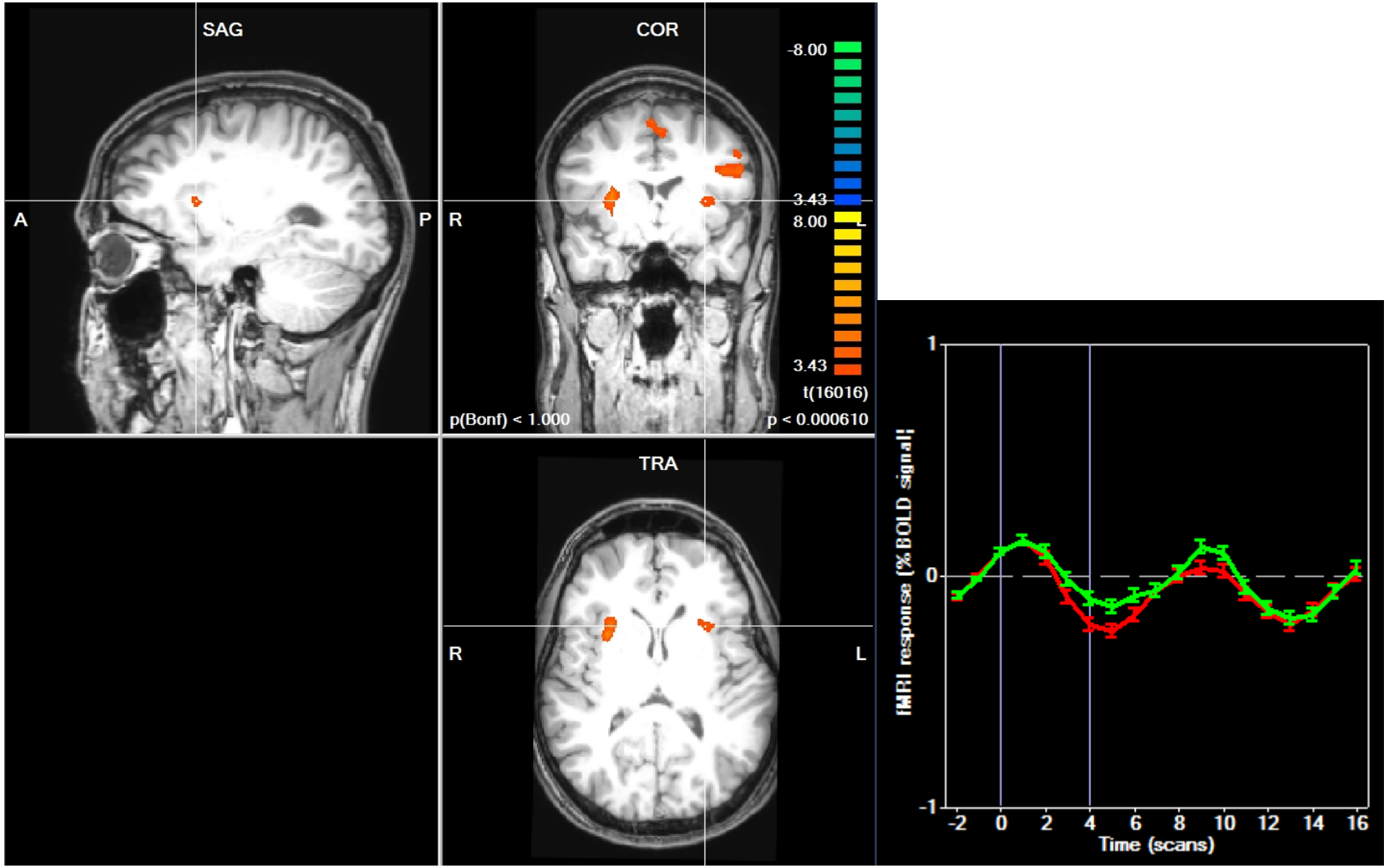

Figure 4-9. The significant activation in the left claustrum (Lclaus), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

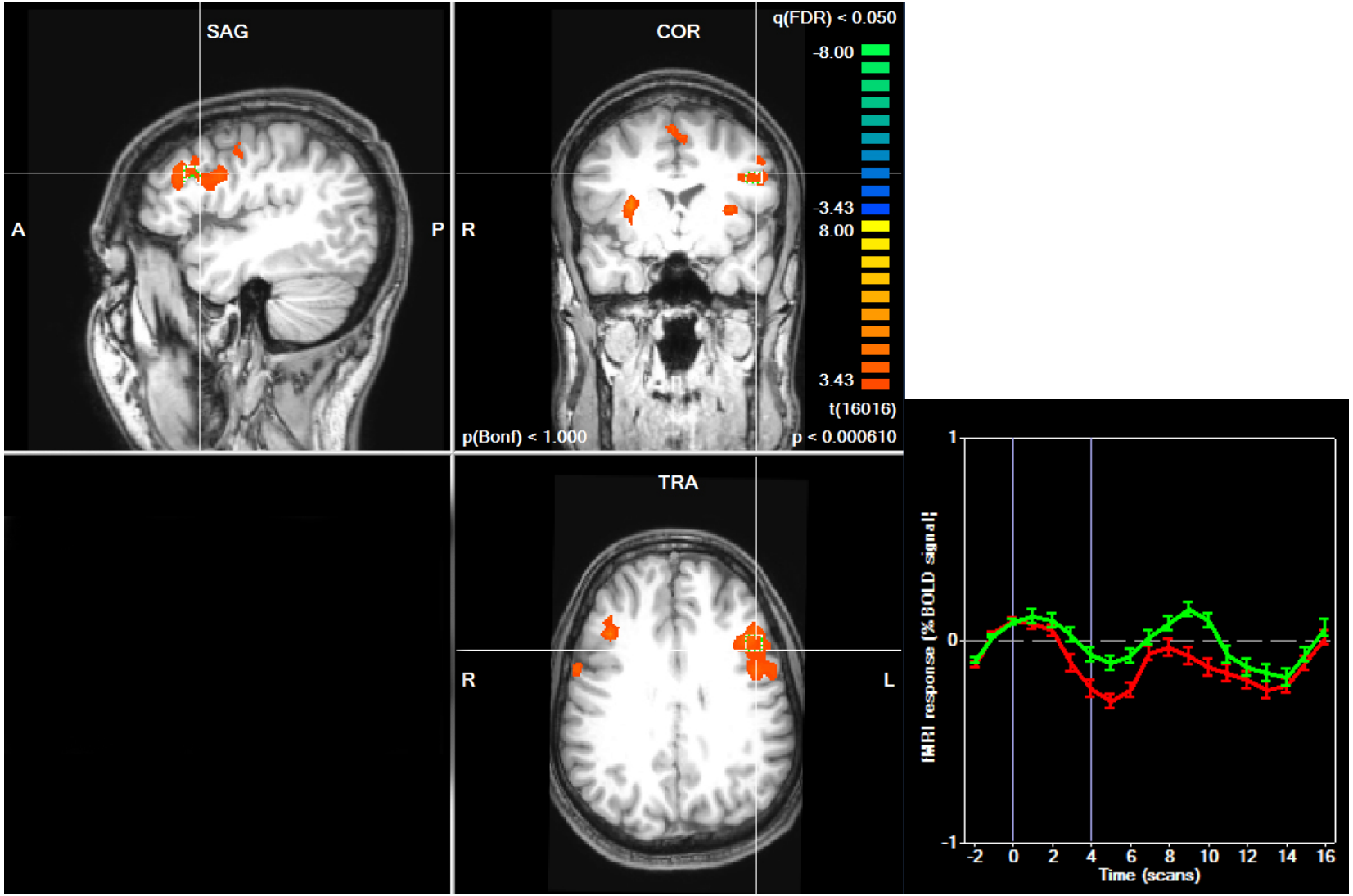

Figure 4-10. The significant activation in the left middle frontal gyrus (LMFG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

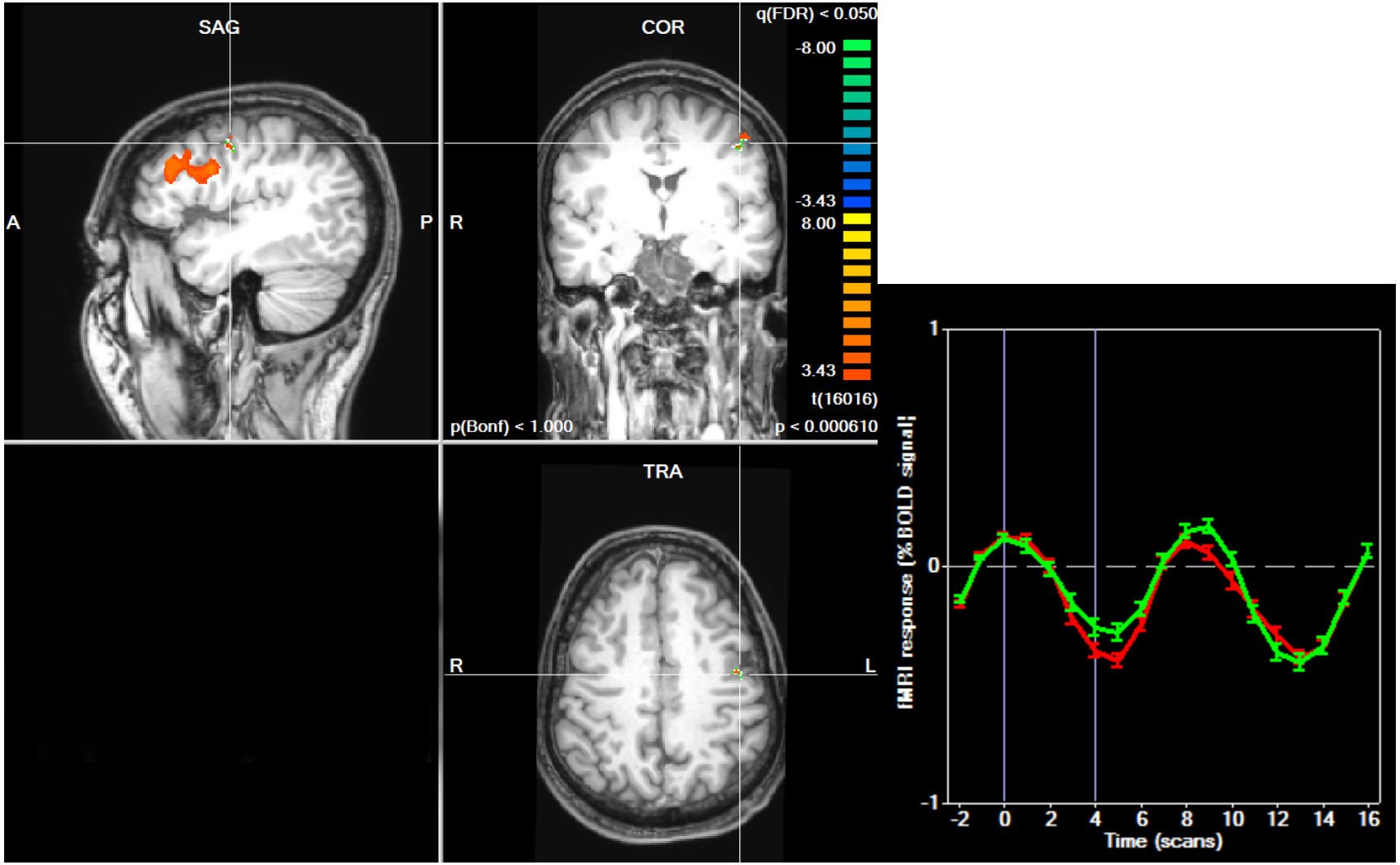

Figure 4-11. The significant activation in the left precentral gyrus (LPreCG), along with the event-related averaging plot of the same region (green signifying the time course of activation for the plausible condition, red the implausible).

CHAPTER 5
DISCUSSION

Behavioral Data

Consistent with the pretests, there were no significant differences in RT or accuracy between conditions. Therefore, it could be reasonably concluded that there was no overall increase in difficulty between processing one versus processing the other condition; this conclusion would be based on offline measures of processing, but provides evidence that trials of different conditions did not differ in terms of overall difficulty or processing load. Ferstl (2007) interprets inferior frontal gyrus (IFG) activation as a measure of increasing processing demand or difficulty; coupling this interpretation with our behavioral data, and the fact that we do not find IFG activation for either contrast lends credence to the interpretation that both conditions are processed with equal or nearly equal demands on processing resources.

Imaging Data

One of the more important results of this study has been the limited RH activation seen. Even for the plausible condition, in which coherent discourse models could be built, RH-dominant activation is not seen. With the exception of the RSTG, all RH activations are bilateral in nature.

Bilateral Activations

These bilateral activations are interesting; their interpretation is up for debate. For the RPreCG, we see greater activation in the RH than the LH, though our participants all used their right hand to respond to the task in all conditions (and therefore, should activate their LPreCG, as the contralateral hemisphere controls motor response). One possible explanation for the differential LPreCG activation is that participants are more certain of their decision for one condition over the other. If this is the case, they might initially recruit a bilateral area (the

RPreCG) to try and assist with the decision of which finger to use. Feedback from the RPreCG might in turn increase activation in the LPreCG, leading to the contrast we see.

Ferstl, Rinck, and Von Cramon (2005) found activation in the R IFG/PreCG junction for inconsistent > consistent trials, but only in contrasting one of their conditions. They attribute this activation to more demands on inferencing processes when inconsistencies are present. The current study also found activation in the R PreCG, but for plausible > implausible trials. Since the behavioral data show no significant difference in either accuracy or RT, we cannot automatically conclude that there was a dramatic increase in difficulty for the plausible condition resulting in more activation in this area. What might instead be happening is a decision or integration effect – in that the RPreCG would assist with the decision-making process of which finger to respond with.

Right Superior Temporal Gyrus

The activation in the RSTG would seem to support the RH discourse processing model, as it does not have a LH homologue, but its extent is small. Meyer, Friederici, and Von Cramon (2000) have implicated the RaTL in assisting its LH counterpart when processing difficulties occur, but in the present study we find activation more toward the middle of the R STG, and for the plausible condition as opposed to the implausible. Their analysis would not seem to apply here, as we see neither bilateral or LH activation, and according to our behavioral data, participants did not have significantly more trouble with one condition over another. Ferstl, Rinck, and Von Cramon (2005) found activation in the RaTL (slightly more anterior than current results) to be associated with local detection of inconsistencies, at the propositional level of processing. As Ferstl (2007) interprets this finding, we might see this activation due to successful proposition building for the plausible condition. For the implausible condition, when participants begin processing the second sentence of trial and encounter an anomaly, they may stop forming

propositions and integrating the rest of the sentence. This conclusion is supported by ERP evidence, as well. When readers are presented with a combination of a syntactic and semantic violation, they do not produce neural responses for the semantic violation (where an N400 component is normally expected). Only "syntactic" neural responses (an ELAN and a P600 component) for the violation are seen (Friederici 2001).

Prefrontal Cortex

The prefrontal cortex makes up the remainder of the areas differentially activated for the plausible condition. With the exception of a small (439 voxels) activation of the RMFG, activation is almost exclusively seen in the LH – the SFG (BA 6), the MedFG (BA 6), and the LMFG (BA 9). The LH medial frontal lobe has already been implicated in the plausibility judgment task (Stowe et al. 2004), so it does not come as a total surprise that there is activation in this area. Ferstl and Von Cramon (2001) also saw activation in this area for coherent > incoherent trials. An interpretation as to why there is more activation for the plausible > implausible condition might be the more integratory process of judging something as plausible. If a sentence or discourse is implausible, the participant has to recognize just one implausible feature to make a decision. On the other hand, to judge a sentence as plausible, the participant has to check and integrate all features of the sentence, then make a decision. This activation for the plausible condition might reflect this type of processing strategy for the task at hand.

Kuperberg et al. (2006) make a similar argument in looking at anomaly processing. In mapping new information onto information in semantic memory and determining normalcy, these researchers saw more activation in the left frontal and temporal areas to pragmatically anomalous sentences > normal sentences. In fact, they state that it requires more effort to judge a sentence implausible on pragmatic grounds rather than plausible. While that may be true for sentence processing in isolation, this interpretation does not seem to mesh well with our results.

Given the way our experimental conditions were formulated and that participants could potentially judge by the fifth frame the (im)plausibility of the trial as a whole, it would not be logical to assume participants continued incorporating the rest of the sentence once judgment had passed. We also cued participants to respond, which could be masking the early resolution of some implausible trials. The remainder of activation seen in the prefrontal cortex could be ascribed to inferencing generation (e.g. Mason and Just 2004, Ferstl and Von Cramon 2001). Xu and colleagues (2005) found activation in this area as well, selectively for the narrative condition (to the exclusion of their sentence activation).

So this differential activation seen for the plausible condition might not, in fact, be due wholly to (automatic) inferencing processes, but also to the final integration of propositions present in the discourse. In other words, because a final construction or interpretation is possible with the plausible condition, and such an interpretation cannot be constructed for the implausible condition (as it does not make sense, or allow for a final result to be reached), the activation may reflect this incorporation process of arriving at a final, coherent discourse model.

The right hemisphere is undeniably involved in language processing. However, to attribute discourse processing as a whole to the hemisphere is not warranted by the data presented in the literature, nor is that view supported by the data presented in the current study. Two interpretations are possible with the present data. First, the RH is not as involved in discourse processing as previously thought – in that it does not specialize in multi-sentence processing. The second interpretation possible is that the RH plays a larger role in discourse processing when there are a larger amount of sentences (and propositions) in discourse than the two-sentence discourses used in our study. These two interpretations are not mutually exclusive; this second hypothesis also gives support for a less specialized view of the processes occurring in the RH. As

the amount of sentences increases in a discourse, the WM load increases as well. Activation in this case would naturally be found in the RH (as it has been shown that the RH supports LH processing when processing load increases (Ferstl and von Cramon 2001)). Based on the evidence presented so far, both in the literature and in the present study, we cannot conclude that the right hemisphere specializes in discourse processing.

Limitations and Future Experiments

There are limitations in every experiment, and this one is no exception to the rule. We were interested in examining (problems with) reference processing in discourse, and designed our experiment accordingly. Our results indicated that the RH does not hold a monopoly over discourse processing as a whole. Due to the fact that participants were cued to respond at the end of a trial, we cannot be sure at what point they recognized the implausibility. We therefore do not know (if they recognized it early in the second sentence) whether they processed the remainder of the sentence or not. Future experiments could help ascertain the answer to this question. Presenting the same materials in the same way but giving participants a different task might yield insight into this limitation. For instance, instead of asking for a plausibility judgment, participants could be asked about a feature that appears (or does not) in the second sentence (e.g. *Had all tenants lived there for many years?* (see Table 3-1, distractor type 4)).

Another further avenue of research would be investigating exactly what areas are activated for the creation of new discourse referents. Such an experiment would have to take into account the automatic generation of referents associated with noun phrases, and utilize anaphora (or words such as quantifiers that can function as anaphora). No experiment has looked at this specific process so far, and the results from such an experiment would allow researchers to begin to understand the beginnings of the conglomeration of processes which allow humans to process language in context.

APPENDIX A
LIST OF MATERIALS USED

Table A-1 List 1, Run 1 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Four drinks are being filled up. All four will be for the thirsty athletes.	2
b	Three skirts are on sale today. All three are way too expensive for me.	2
b	Eight ducks are in the pond. All eight are eating bread thrown by kids.	2
b	Eight workers struggled through the day. All eight will be fired later this evening.	2
b	Five squirrels are climbing a tree. All five are holding something in their mouths.	2
c	Four tires were leaking some air. All three had already been patched last week.	3
b	Six cups are in the cabinet. All six just came out of the dishwasher.	2
b	Six eggs are in the carton. All six will be used for the recipe.	2
b	Five poems made my girlfriend cry. All five were really stupid in my opinion.	2
c	Five senators have addressed the issue. All three are working on very important things.	3
c	Six chairs are in the room. All eight are for guests to sit on.	3
c	Three restaurants have opened for business. All five seem like they will make money.	3
c	Eight tiles need to be replaced. All six are covered in very tiny cracks.	3
f1-plaus	Three men were building a house. All six that were watching made many comments.	2
f1-plaus	Four roofs were repaired this week. All eight that were fixed previously still leak.	2
f2-impl	Six channels are dedicated to children. All six have political documentaries and independent films.	3
f2-impl	Three guests did not eat seafood. All three enjoyed the lobster and the shrimp.	3
f2-impl	Five lockers are full of school books. All five are not being used at all.	3
f2-impl	Five movies were shot in color. All five were filmed in black and white.	3
f3-plaus	Few shops sell only kid's clothing. Some have large collections of men's suits.	2
f3-plaus	Many people died in the crash. Few lived to tell about the accident.	2
f3-plaus	These flowers are deadly to animals. All contain toxins that may cause rashes.	2
f3-plaus	Some companies pay employees almost nothing. Some pay a moderate but reasonable salary.	2
f-4imp	Some drivers eat in their cars. Most need their tires rotated each year.	3
f-4imp	These crackers are made from wheat. Most are filled with chunks of ice.	3

Correct Response 2 = plausible, 3 = implausible

Table A-2. List 1, Run 2 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Three sparrows are on the table. All three are begging people for some crumbs.	2
b	Six lawyers worked on the case. All six have just joined the law firm.	2
b	Eight sailboats were in the race. All eight sunk before they crossed the line.	2
b	Three teachers had offered to help. All three would much rather do something else.	2
b	Three companies are in the building. All three will be moving away very soon.	2
b	Five plates broke during the meal. All five fell off of the kitchen table.	2
c	Three viruses have attacked our computer. All four have already caused large scale problems.	3
c	Three journals are in my desk. All five contain all my top secret information.	3
c	Six gifts have been opened already. All four were from my brothers and sisters.	3
c	Eight surfboards are in the display. All five just arrived at the store today.	3
c	Eight frogs jumped into the ditch. All four were looking for some tasty flies.	3
c	Six monkeys have climbed the tree. All eight are busy eating lots of fruit.	3
f1-plaus	Three toddlers were crying very loudly. All six that were quiet before became annoyed.	2
f1-plaus	Eight fans were cheering very loudly. All six who supported the opponent were quiet.	2
f1-plaus	Six cats played with the yarn. All four that were asleep didn't notice anything.	2
f1-plaus	Four storms have passed through here. All three that formed this summer hit elsewhere.	2
f1-plaus	Four elephants were performing an act. All three that performed last year had died.	2
f1-plaus	Six branches are on the tree. All three that touched the roof have been removed.	2
f1-plaus	Three musicians just recorded an album. All five who recorded here before became famous.	2
f3-plaus	Some couples are having minor problems. A few hardly ever talk to each other.	2
f3-plaus	Some peaches were only slightly bruised. Most had completely rotted and were trashed.	2
f-4imp	Most kings lived a long life. All were poisoned by their own servants.	3
f-4imp	Most Mexican sauces are extremely hot. Few are way too spicy to eat.	3
f-4imp	Few fish live in sweet water. Most live in rivers, lakes or ponds.	3
f-4imp	No problem appears to be unsolvable. All seem like they have no solution.	3

Correct Response 2 = plausible, 3 = implausible

Table A-3. List 1, Run 3 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Six waiters have asked to leave. All six are looking for other summer jobs.	2
b	Five flowers are in the vase. All five have already wilted from the heat.	2
b	Four nations have signed the treaty. All four will obey it beginning next year.	2
b	Four vines have covered the gate. All four are now growing down the path.	2
b	Three policemen are making an arrest. All three are holding down a violent suspect.	2
b	Four coaches are pacing the sidelines. All four are too nervous to do anything.	2
c	Three suitcases were on a cart. All six were just taken from baggage claim.	3
c	Four plays moved the entire audience. All six were directed towards very young children.	3
c	Five airplanes have been serviced today. All three needed major repairs that took hours.	3
c	Three authors are writing a book. All five haven't published in a long time.	3
c	Five items are in stock now. All eight have just been received this afternoon.	3
c	Eight dishes are cooking right now. All four take a long time to prepare.	3
f1-plaus	Eight bikes were on the rack. All four that were very expensive were inside.	2
f1-plaus	Five motorcycles raced down the track. All eight that crashed earlier could not start.	2
f1-plaus	Eight girls were on the squad. All five that competed last year had graduated.	2
f1-plaus	Six buses are making their rounds. All three at the station are not running.	2
f1-plaus	Five kids wanted to go outside. All six that were reading didn't want to.	2
f2-impl	Eight students have very good grades. All eight are failing all of their classes.	3
f2-impl	Three pencils have a sharp tip. All three are too dull to write with.	3
f3-plaus	Some truckers were awake all night. Others slept soundly in a comfortable bed.	2
f3-plaus	Some insects are harmless to humans. Others can kill you with one bite.	2
f3-plaus	Most chairs are actually very comfortable. A few are always painful to sit in.	2
f3-plaus	Some cups have broken during shipment. Those in the box are still intact.	2
f3-plaus	Most plants had bright yellow flowers. Some had red petals with purple tips.	2
f-4imp	Some species live in the arctic. All prefer to live in tropical climates.	3

Correct Response 2 = plausible, 3 = implausible

Table A-4. List 1, Run 4 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Eight rats are gnawing on something. All eight are rooting around in the dumpster.	2
b	Four dogs have learned to fetch. All four seemed to have difficulty with it.	2
b	Six plants have died this winter. All six have been kept inside all year.	2
b	Three trains are preparing to depart. All three are still filling up with passengers.	2
b	Five cakes are baking right now. All five will be decorated with white flowers.	2
b	Eight firemen are in the fire. All eight are trying to extinguish the blaze.	2
c	Four notebooks are in my backpack. All three are full of my math notes.	3
c	Eight beers are on the table. All five were just taken from the fridge.	3
c	Eight shirts need to be washed. All six may have to be slightly mended.	3
c	Three songs have made me happy. All five are my best friend's favorite songs.	3
c	Five bears jumped in the stream. All three were looking for something to eat.	3
c	Six programs crashed on the computer. All four were designed to be very stable.	3
c	Four steaks are on the counter. All eight just came off of the grill.	3
f1-plaus	Three tents collapsed in the storm. All six that had flexible poles did not.	2
f1-plaus	Three women were at the table. All five who came earlier had already left.	2
f1-plaus	Four cabs arrived at the airport. All eight that were there earlier had left.	2
f1-plaus	Four girls had shopped all day. All six that were broke stayed at home.	2
f1-plaus	Three courses opened in the department. All five that were taught before are not offered.	2
f2-impl	Eight raccoons were vicious and dangerous. All eight were gentle and loved by everyone.	3
f2-impl	Four essays were an exciting read. All four were dull and I lost interest.	3
f3-plaus	Most printers aren't working at all. Few are running their jobs very smoothly.	2
f3-plaus	These tools are not very expensive. All of them are cheaper than was listed on-line.	2
f3-plaus	Few lectures have sparked my interest. Most were so boring that I slept.	2
f-4imp	Most girls were very strict vegetarians. Few wouldn't eat any meat at all.	3
f-4imp	Many people like to talk a lot. Some usually bring their lunch from home.	3
f-4imp	Most knives are made of metal. Some are used to sift fine flour.	3

Correct Response 2 = plausible, 3 = implausible

Table A-5. List 1, Run 5 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Three roses bloomed in our garden. All three will need a lot of care.	2
b	Eight mice are running around me. All eight have been hiding during the daytime.	2
b	Six researchers analyzed all the data. All six worked on making charts and graphs.	2
b	Four designs are in the catalog. All four can be seen on the website.	2
b	Three actors read their new script. All three couldn't seem to remember their lines.	2
b	Five turtles are swimming under water. All five are looking for something to eat.	2
c	Three folders are on my desk. All four belong to one of my classmates.	3
c	Six pigs are in the pen. All three are eating out of a bucket.	3
c	Four packages were shipped last night. All eight have deadlines at ten this morning.	3
c	Six brands have sold out quickly. All three are the most expensive ones available.	3
c	Five players are on the court. All three had been sitting on the bench.	3
c	Four helicopters have conducted the tour. All six are usually used to cover traffic.	3
c	Five prisoners are hoping for release. All eight have much more time to serve.	3
f1-plaus	Five paintings had sold very quickly. All three that I like are still there.	2
f1-plaus	Six ships were in the port. All four that had left earlier had not returned.	2
f1-plaus	Three classes have been very helpful. All four that I took before were useless.	2
f1-plaus	Eight copies were smudged with ink. All four that I made earlier were useless.	2
f1-plaus	Five singers have asked to perform. All three who had been invited had cancelled.	2
f3-plaus	Most homes were very badly damaged. Few didn't have a scratch on them.	2
f3-plaus	Most boxes are full of clothes. Some are only holding a few things.	2
f-4imp	All cutting boards were completely round. Some were shaped like a perfect square.	3
f-4imp	Some sausages are made of pork. Some are made of raw cow's milk.	3
f-4imp	Some people are afraid of snakes. Some are scared of mice and cheese.	3
f-4imp	Some classes are taught for free. None can be attended without paying anything.	3
f-4imp	Some stamps are saved by collectors. They use them to mail their bills.	3
f-4imp	Some tenants have just moved in. All have lived here for many years.	3

Correct Response 2 = plausible, 3 = implausible

Table A-6. List 2, Run 1 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Six chairs are in the room. All six are for guests to sit on.	2
b	Three poachers hunted during the night. All three were stopped by the park ranger.	2
b	Three restaurants have opened for business. All three seem like they will make money.	2
b	Eight tiles need to be replaced. All eight are covered in very tiny cracks.	2
b	Four tires were leaking some air. All four had already been patched last week.	2
b	Five senators have adressed the issue. All five are working on very important things.	2
c	Four drinks are being filled up. All eight will be for the thirsty athletes.	3
c	Three skirts are on sale today. All four are way too expensive for me.	3
c	Eight ducks are in the pond. All six are eating bread thrown by kids.	3
c	Eight workers struggled through the day. All four will be fired later this evening.	3
c	Five squirrels are climbing a tree. All three are holding something in their mouths.	3
c	Six cups are in the cabinet. All eight just came out of the dishwasher.	3
c	Six eggs are in the carton. All three will be used for the recipe.	3
c	Five poems made my girlfriend cry. All three were really stupid in my opinion.	3
f1-plaus	Three men were building a house. All six that were watching made many comments.	2
f1-plaus	Four roofs were repaired this week. All eight that were fixed previously still leak.	2
f2-impl	Six channels are dedicated to children. All six have political documentaries and independent films.	3
f2-impl	Three guests did not eat seafood. All three enjoyed the lobster and the shrimp.	3
f2-impl	Five lockers are full of school books. All five are not being used at all.	3
f2-impl	Five movies were shot in color. All five were filmed in black and white.	3
f3-plaus	Many people died in the crash. Few lived to tell about the accident.	2
f3-plaus	These flowers are deadly to animals. All contain toxins that may cause rashes.	2
f3-plaus	Some companies pay employees almost nothing. Some pay a moderate but reasonable salary.	2
f3-plaus	Few shops sell only kid's clothing. Some have large collections of men's suits.	2
f-4imp	These crackers are made from wheat. Most are filled with chunks of ice.	3
f-4imp	Some drivers eat in their cars. Most need their tires rotated each year.	3

Correct Response 2 = plausible, 3 = implausible

Table A-7. List 2, Run 2 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Three viruses have attacked our computer. All three have already caused large scale problems.	2
b	Three journals are in my desk. All three contain all my top secret information.	2
b	Six gifts have been opened already. All six were from my brothers and sisters.	2
b	Eight surfboards are in the display. All eight just arrived at the store today.	2
b	Eight frogs jumped into the ditch. All eight were looking for some tasty flies.	2
b	Six monkeys have climbed the tree. All six are busy eating lots of fruit.	2
c	Three teachers had offered to help. All five would much rather do something else.	3
c	Three companies are in the building. All five will be moving away very soon.	3
c	Five plates broke during the meal. All eight fell off of the kitchen table.	3
c	Three sparrows are on the table. All six are begging people for some crumbs.	3
c	Six lawyers worked on the case. All three have just joined the law firm.	3
c	Eight sailboats were in the race. All five sunk before they crossed the line.	3
f1-plaus	Three musicians just recorded an album. All five who recorded here before became famous.	2
f1-plaus	Eight fans were cheering very loudly. All six who supported the opponent were quiet.	2
f1-plaus	Six cats played with the yarn. All four that were asleep didn't notice anything.	2
f1-plaus	Four storms have passed through here. All three that formed this summer hit elsewhere.	2
f1-plaus	Four elephants were performing an act. All three that performed last year had died.	2
f1-plaus	Six branches are on the tree. All three that touched the roof have been removed.	2
f1-plaus	Three toddlers were crying very loudly. All six that were quiet before became annoyed.	2
f3-plaus	Some peaches were only slightly bruised. Most had completely rotted and were trashed.	2
f3-plaus	Some couples are having minor problems. A few hardly ever talk to each other.	2
f-4imp	Most kings lived a long life. All were poisoned by their own servants.	3
f-4imp	Most Mexican sauces are extremely hot. Few are way too spicy to eat.	3
f-4imp	Few fish live in sweet water. Most live in rivers, lakes or ponds.	3
f-4imp	No problem appears to be unsolvable. All seem like they have no solution.	3

Correct Response 2 = plausible, 3 = implausible

Table A-8. List 2, Run 3 Materials, sorted by condition.

Condition	Stimulus	Correct Response
b	Three suitcases were on a cart. All three were just taken from baggage claim.	2
b	Four plays moved the entire audience. All four were directed towards very young children.	2
b	Five airplanes have been serviced today. All five needed major repairs that took hours.	2
b	Three authors are writing a book. All three haven't published in a long time.	2
b	Five items are in stock now. All five have just been received this afternoon.	2
b	Eight dishes are cooking right now. All eight take a long time to prepare.	2
c	Four coaches are pacing the sidelines. All six are too nervous to do anything.	3
c	Six waiters have asked to leave. All four are looking for other summer jobs.	3
c	Five flowers are in the vase. All eight have already wilted from the heat.	3
c	Four nations have signed the treaty. All six will obey it beginning next year.	3
c	Four vines have covered the gate. All three are now growing down the path.	3
c	Three policemen are making an arrest. All five are holding down a violent suspect.	3
f1-plaus	Five motorcycles raced down the track. All eight that crashed earlier could not start.	2
f1-plaus	Eight girls were on the squad. All five that competed last year had graduated.	2
f1-plaus	Six buses are making their rounds. All three at the station are not running.	2
f1-plaus	Five kids wanted to go outside. All six that were reading didn't want to.	2
f1-plaus	Eight bikes were on the rack. All four that were very expensive were inside.	2
f2-impl	Eight students have very good grades. All eight are failing all of their classes.	3
f2-impl	Three pencils have a sharp tip. All three are too dull to write with.	3
f3-plaus	Some truckers were awake all night. Others slept soundly in a comfortable bed.	2
f3-plaus	Some insects are harmless to humans. Others can kill you with one bite.	2
f3-plaus	Most chairs are actually very comfortable. A few are always painful to sit in.	2
f3-plaus	Some cups have broken during shipment. Those in the box are still intact.	2
f3-plaus	Most plants had bright yellow flowers. Some had red petals with purple tips.	2
f-4imp	Some species live in the arctic. All prefer to live in tropical climates.	3

Correct Response 2 = plausible, 3 = implausible

Table A-9. List 2, Run 4 Materials sorted by condition.

Condition	Stimulus	Correct Response
b	Four notebooks are in my backpack. All four are full of my math notes.	2
b	Eight beers are on the table. All eight were just taken from the fridge.	2
b	Eight shirts need to be washed. All eight may have to be slightly mended.	2
b	Three songs have made me happy. All three are my best friend's favorite songs.	2
b	Five bears jumped in the stream. All five were looking for something to eat.	2
b	Six programs crashed on the computer. All six were designed to be very stable.	2
b	Four steaks are on the counter. All four just came off of the grill.	2
c	Five cakes are baking right now. All three will be decorated with white flowers.	3
c	Eight firemen are in the fire. All six are trying to extinguish the blaze.	3
c	Eight rats are gnawing on something. All five are rooting around in the dumpster.	3
c	Four dogs have learned to fetch. All three seemed to have difficulty with it.	3
c	Six plants have died this winter. All eight have been kept inside all year.	3
c	Three trains are preparing to depart. All four are still filling up with passengers.	3
f1-plaus	Three courses opened in the department. All five that were taught before are not offered.	2
f1-plaus	Three tents collapsed in the storm. All six that had flexible poles did not.	2
f1-plaus	Three women were at the table. All five who came earlier had already left.	2
f1-plaus	Four cabs arrived at the airport. All eight that were there earlier had left.	2
f1-plaus	Four girls had shopped all day. All six that were broke stayed at home.	2
f2-impl	Eight raccoons were vicious and dangerous. All eight were gentle and loved by everyone.	3
f2-impl	Four essays were an exciting read. All four were dull and I lost interest.	3
f3-plaus	Most printers aren't working at all. Few are running their jobs very smoothly.	2
f3-plaus	Few lectures have sparked my interest. Most were so boring that I slept.	2
f3-plaus	These tools are not very expensive. All of them are cheaper than was listed on-line.	2
f-4imp	Most girls were very strict vegetarians. Few wouldn't eat any meat at all.	3
f-4imp	Many people like to talk a lot. Some usually bring their lunch from home.	3
f-4imp	Most knives are made of metal. Some are used to sift fine flour.	3

Correct Response 2 = plausible, 3 = implausible

Table A-10. List 2, Run 5 Materials sorted by condition.

Condition	Stimulus	Correct Response
b	Six pigs are in the pen. All six are eating out of a bucket.	2
b	Four packages were shipped last night. All four have deadlines at ten this morning.	2
b	Six brands have sold out quickly. All six are the most expensive ones available.	2
b	Five players are on the court. All five had been sitting on the bench.	2
b	Four helicopters have conducted the tour. All four are usually used to cover traffic.	2
b	Three folders are on my desk. All three belong to one of my classmates.	2
b	Five prisoners are hoping for release. All five have much more time to serve.	2
c	Three roses bloomed in our garden. All six will need a lot of care.	3
c	Eight mice are running around me. All four have been hiding during the daytime.	3
c	Six researchers analyzed all the data. All four worked on making charts and graphs.	3
c	Four designs are in the catalog. All eight can be seen on the website.	3
c	Three actors read their new script. All five couldn't seem to remember their lines.	3
c	Five turtles are swimming under water. All three are looking for something to eat.	3
f1-plaus	Three classes have been very helpful. All four that I took before were useless.	2
f1-plaus	Eight copies were smudged with ink. All four that I made earlier were useless.	2
f1-plaus	Five singers have asked to perform. All three who had been invited had cancelled.	2
f1-plaus	Five paintings had sold very quickly. All three that I like are still there.	2
f1-plaus	Six ships were in the port. All four that had left earlier had not returned.	2
f3-plaus	Most homes were very badly damaged. Few didn't have a scratch on them.	2
f3-plaus	Most boxes are full of clothes. Some are only holding a few things.	2
f-4imp	All cutting boards were completely round. Some were shaped like a perfect square.	3
f-4imp	Some sausages are made of pork. Some are made of raw cow's milk.	3
f-4imp	Some people are afraid of snakes. Some are scared of mice and cheese.	3
f-4imp	Some classes are taught for free. None can be attended without paying anything.	3
f-4imp	Some stamps are saved by collectors. They use them to mail their bills.	3
f-4imp	Some tenants have just moved in. All have lived here for many years.	3

Correct Response 2 = plausible, 3 = implausible

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BIOGRAPHICAL SKETCH

Nicole A. Chevalier was born and raised in South Florida, where she lived until attending college. She received her Bachelor of Arts in linguistics from the University of Florida in 2006, with a minor in medieval and early modern studies. She received her Master of Arts degree from UF in 2008.