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Individual differences in the use of context to resolve a homonym’s meaning

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**Abstract**

**Introduction**

Language is typically processed in context, such as within phrases, sentences, or a discourse. Contextual information during language processing can provide listener or readers with important information about meaning. For example, when a reader encounters a semantically ambiguous word such as the homonym “pen” preceding contextual information can be used to determine whether “pen” refers to PEN(animal cage) or a PEN(writing instrument) (throughout this paper we use capital letters to indicate a homonym, and brackets to refer to a semantic representation). This paper investigates the neural mechanisms that support the process of using contextual information to resolving meaning.

Neuroimaging investigations on the role of contextual information for homonym comprehension have suggested that individuals recruit posterolateral temporal (Rodd et al., 2005b; Gennari et al., 2007; Zempleni et al., 2007b) and inferior frontal cortex (IFC; BA 45) (Rodd et al., 2005a; Mason and Just, 2007; Zempleni et al., 2007a; Grindrod et al., 2008a; Whitney et al., 2009) to determine a homonym’s meaning. Posterolateral temporal cortex activation is consistent with other investigations revealing increased activation in left posterolateral temporal cortex for lexical semantic processing relative to syntactic processing during sentence comprehension (Ni et al., 2000; Friederici et al., 2003; Humphries et al., 2006). Likewise, patient studies have associated lexical semantic processing difficulty with superior temporal disease in the left hemisphere (Warrington and Shallice, 1984; Hillis et al., 2001).

IFC activation is consistent with studies of semantic processing that suggest this region supports a cognitive control mechanism that mediates the selection and retrieval of competing semantic alternatives (Thompson-Schill et al., 1997a; Badre and Wagner, 2002). For example, in priming tasks IFC is recruited when a homonym is primed by a subordinate meaning (e.g., “dance”-“ball”) compared to a dominant meaning (e.g., “game”-“ball”) and this activation pattern is hypothesized to support a controlled strategic search for a subordinate meaning when the dominant meaning is inappropriate (Whitney et al., 2009). In a sentence comprehension study (Zempleni et al.) (2007) embedded a homonym in a subordinate meaning context and compared this to activation when the homonym was embedded in a dominant meaning context. They observed increased activation in bilateral IFC and argue that this finding is consistent with previous research implicating the role of IFC as a mediator for resolving conflict between competing semantic interpretations.

Two studies have suggested that the recruitment of IFC to support homonym comprehension differs across individuals (Mason and Just, 2007; Bedny et al., 2008). In an fMRI study Mason & Just (2007) observed that IFC recruitment during the reading of sentences containing a homonym was modulated by individual differences in reading span, a measure of working memory. Specifically, individuals with lower reading span scores upregulated right IFC. Mason & Just (2007) argued that this additional contralateral recruitment supports the additional working memory resources required to maintain multiple potential homonym interpretations when individuals have insufficient working memory spans to resolve the competing interpretations in left IFC. However, while working memory span influences the extent of IFC activation, it is an indirect measure of how individuals interpreted homonyms.

In an fMRI adaptation study Bedny et al. (2008) presented participants with two sequential word pairs containing either a repeated homonym that had consistent meaning (e.g., “pig-pen”-“cage-pen”) or an inconsistent meaning (e.g., “office-pen”-“cage-pen”) and asked participants to judge whether the words within each pair were related. They observed greater recruitment of IFC in the inconsistent compared to the consistent condition which they suggest is related to increased semantic competition - a pattern that is consistent with the previously described studies. Critically, they observed a wide-range in accuracy performance on the semantic relatedness judgments whereby some participants were much better at judging the consistent pairs as semantically-related than they were at judging the inconsistent pairs. A correlation analysis demonstrated that this behavioral difference within individuals positively correlated with activation in the left pars opercularis, a subregion of IFC. This finding suggests that individuals who experienced greater competition during inconsistent trials (i.e. made more errors) upregulated IFC to support the resources associated with increased semantic competition demands.

However, while Bedny et al. (1997) investigated individual differences using a direct measure of homonym comprehension, they limited their individual differences analysis to only include IFC and it is possible that there are individual differences in the recruitment of other cortical regions. For example, other investigations on individual differences in language processing have suggested that, depending on the strategy adopted during comprehension, dorsolateral prefrontal cortex (DLPFC) is recruited (REFS). Niewland et al (2007) presented participants with ambiguous sentences containing a pronoun and observed that those readers who used a sentence-external strategy (e.g., ) recruited DLPFC while those readers using a sentence-internal strategy (e.g., ) did not.

This paper aims to investigate how context is used to resolve a homonym’s meaning by monitoring BOLD fMRI in a forced-choice sentence completion task. Forced choice completion tasks require participants to search their semantic space for the possible interpretations of alternative choices. In our task we presented participants with a context sentence (e.g., “Kim had pigs.”) and a completion sentence (e.g., “He needed a \_\_\_\_\_”.). We then asked participants to complete the sentence with either a homonym (e.g., “pen”) or a semantically-related alternative (e.g., “cage”). If participants completed the sentence using a homonym then it suggests that they did not appreciate that the homonym could have an alternative meaning. If, however, participants selected a semantic alternative then it suggests that the reader appreciated both meanings of the homonym. Additionally, we manipulated whether the context

sentence referred to the subordinate or the dominant meaning. In the dominant context retrieval of the subordinate homonym meaning is not necessary since the sentence is consistent with the preferred meaning of the homonym, however, the in the subordinate context it is necessary to process both the less preferred and more preferred homonym meanings. We predict that in subordinate context readers will recruit neural mechanisms to support increased competition between competing semantic alternatives and that these mechanisms may be situated in IFC and DLPFC.

**Methods**

*Participants*

18 healthy young adults (11 female; mean age=25.3 years; mean education=15.1 years) from the University of Pennsylvania community participated in the study for monetary payment. All participants were native speakers of English, right-handed, and in good health with no history of neurological or psychiatric difficulty. Informed consent was obtained from all participants according to a protocol approved by the University of Pennsylvania Institutional Review Board. We excluded one participant from our analyses due to data corruption and therefore all results reported are for 17 participants.

*Experimental Materials*

We determined the preferred meanings of 50 noun-noun homonyms (e.g., “pen”) in a free association task in which 20 native English-speaking adults listed the first four words that came to mind. From this list we identified 20 homonyms which yielded 90% or more of total responses referring to one meaning (e.g., for “pen,” responses like “ink”, “pencil”, “paper”) and 10% or fewer total responses referring to another meaning (e.g., for “pen”, responses like “pig”, “sheep”, “farm”). We refer to the former as the *dominant* meaning and the latter as the *subordinate* meaning. We limited our selection of homonyms to 20 items because this subset of pretested homonyms contained a clear dominant and subordinate meaning and this number of items constitutes the minimum number needed to interpret data collected in an fMRI experiment with sufficient statistical power while minimizing the scan duration for the participant’s comfort.

We also generated 2 *context sentences* for each homonym (e.g., “Kim had some X”). As summarized in Table 1, the final word was semantically-related to the dominant meaning of the homonym in 20 context sentences (e.g., for PEN(writing instrument), “ink”); in another 20 context sentences, the final word was related to the subordinate meaning of the homonym (e.g., for PEN(animal cage), “pigs”). The semantic-relatedness of each biasing word relative to each homonym was evaluated on a 1 (unrelated) -7 (related) scale in a pretest completed by 20 different native English-speaking adults. This pretest revealed that the dominant-homonym pairs (e.g., ink-pen) were as semantically related as the subordinate-homonym pairs (e.g., pigs-pen; t(19)=1.39, p=0.2). The materials generated to create the dominant and subordinate context sentences thus are sufficiently semantically-related to bias the reader toward the intended meaning of the context for each homonym.

We also generated a semantically-neutral *carrier sentence* for each homonym that consisted of a simple phrase followed by a blank space (e.g., “She needed a \_\_\_\_\_.”). As indicated in Table 1, the same carrier sentence was used for both contexts (dominant, subordinate) of each homonym.

Lastly, we generated semantically-related *unambiguous alternatives* (e.g., “quill” and “cage”) for each meaning of each homonym (e.g., PEN). These were determined by presenting a cohort of 20 different native English-speaking adults each context sentence and carrier sentence containing the homonym (e.g., “Kim had some ink. She needed a pen”) and instructing them to replace each underlined word with a related word that maintains the same meaning of the sentence. We selected the most frequent response produced across participants that is not itself a homonym (e.g., “quill”). These responses did not differ statistically in lexical frequency (Francis et al., 1982) from the homonym in the dominant [t(19)=1.75, p=0.1] and subordinate contexts [t(19)=1.64, p=0.1].

Using these materials we generated a total of 40 experimental trials composed of 20 homonyms repeated in each of the two contexts (dominant, subordinate), as in Table 1. The same 20 homonyms were intentionally repeated in each context to minimize the possibility that differences observed across each context were due to the explicit context manipulation rather than due to potential differences in the choice of homonym in the experimental materials. In each experimental trial, participants were presented successively with a homonym and an unambiguous alternative, a context sentence, and a carrier sentence.

In order to obscure the repetition of each homonym across the experimental contexts we also generated an additional 200 filler trials that followed the same format as the experimental trials but did not include a homonym (e.g., “Tom loved breakfast. He ate a donut/bagel”). The large ratio of 1 experimental homonym trial to 5 filler trials was used in an attempt to limit the participants’ ability to simply perform a homonym detection task.

*Experimental Procedure*

We used a forced choice sentence completion paradigm. Participants were told that their task was to help us generate materials for a new experiment. They were further instructed “to be careful because some words like ‘pitcher’ can be ambiguous. An ambiguous word is a word that has more than one meaning”. They were given feedback for one trial and then performed another 8 practice trials without feedback.

For each experimental trial, participants were presented with three events; once each event was presented, it remained on the screen for the duration of the trial. This presentation method was used to minimize the amount of task-related executive resources that were required to perform the task (e.g., working memory to recall a previous event). As illustrated in Figure 1, the first event presented two written choices, one homonym (e.g., “pen”) and one unambiguous alternative (e.g., “quill”), in a counterbalanced placement on the left or right of the screen for 3000msec. In the second event, participants were presented with a written context sentence (e.g, “Kim had some ink”) for 3000msec. In the third event, participants were presented with the written carrier sentence (e.g, “She needed a \_\_\_\_.”) for 3000msec. Participants completed the sentence by responding with a left or right button press using a fiber-optic response pad to indicate the word they preferred to complete the carrier sentence. We report the proportion of unambiguous alternative responses.

Experimental and filler items were randomly distributed into 5 equal length runs with a duration of 9 minutes and counterbalanced so that each run contained the same proportion of each trial type and only included one presentation of each homonym. Within each trial, each event including the presentation of choices, context sentence, and completion sentence was presented synchronously with the onset of the MRI scanner TR (3000ms).

*MRI Acquisition & Analysis*

Scans were acquired on a Siemens 3.0T Trio scanner. Each session began with acquisition of a high-resolution T1-weighted structural volume using an MPRAGE protocol (TR = 1620 ms, TE = 3 ms, flip angle = 15°, 1 mm slice thickness, 192 × 256 matrix, resolution = .9766 × .9766 × 1 mm). A total of 955 BOLD fMRI images were acquired in 5 separate runs of equal length. Each image was acquired with fat saturation, 3 mm isotropic voxels, flip angle of 15°, TR = 3 s, TEeff = 30 ms, and a 64 × 64 matrix.

Image preprocessing and statistical analyses were performed using SPM5 (Wellcome Trust Centre for Functional Neuroimaging, London, UK). We first modeled each individual participant’s data. Low-frequency drifts were removed with high-pass filtering using a cutoff period of 128 s and autocorrelations were modeled using a first-order autoregressive model. Images for each participant were realigned to the first image in the series (Friston et al., 1995) and coregistered with the structural image (Ashburner and Friston, 1997). The transformation required to bring a participant’s images into standard MNI152 space was calculated using tissue probability maps (Ashburner & Friston, 1997), and these warping parameters were then applied to all functional images for that participant. During spatial normalization, functional data were interpolated to isotropic 2 mm voxels. The data were spatially smoothed with an 8 mm FWHM isotropic Gaussian kernel.

For each stimulus category, hemodynamic response was estimated by convolving the onset times of the explicit decision event with a canonical hemodynamic response function. A general linear model approach was used to calculate parameter estimates for each variable for each subject, and linear contrasts for comparisons of interest. These estimates were then entered into second-level random effects analyses to allow us to make inferences across participants. In our initial analyses we report regions of activation relative to a resting baseline which survive a height threshold of t>5.96 (p<0.0001 uncorrected) and in the direct subtractions of closely matched materials we report regions of activation that survive a height threshold of t>4.01 (p<0.0005 uncorrected). In all comparisons we report clusters that contain a minimum of 20 adjacent voxels and have a peak voxel that exceeds a statistical cut-off criterion of p<0.05 (FDR-corrected).

**Results**

*Behavioral results*

We found that participants select single-meaning alternatives more in the subordinate context than in the dominant context, although this difference was not reliable across the entire group of participants [t(16)=1..29, p>0.1]. All behavioral results are summarized in Table 2. The range of the participant’s rate of selecting unambiguous alternatives was very large (33-100%), suggesting that there may be individual differences in a participant’s likelihood to choose an unambiguous alternative to a homonym in a subordinate context. To further investigate whether there are different patterns of performance on the task, we first calculated the chance rate of selecting one of two responses using a binomial test. This test revealed that selecting 14 (70%) or more alternatives out of 20 possible responses per condition differs significantly from chance (p<0.05). We then created two subgroups of participants using a criterion of a 70% alternative selection rate. This revealed that 10 participants significantly select alternatives to a homonym with a single associated meaning in the subordinate context at a level that exceeds chance, and that 7 participants did not differentially prefer a single-meaning alternative to a homonym in the subordinate condition. We refer to these subgroups as “strategizers” and “non-strategizers”, respectively.

An analysis of the mean rate of alternative selections in the subgroups revealed that strategizers significantly select alternatives more than non-strategizers in both the dominant [t(15)=4.31, p<0.001] and subordinate [t(15)=2.22, p<0.05] contexts. Within each subgroup, participants selected alternatives at a consistent rate across both the dominant and subordinate contexts: strategizers [t(9)<1, ns] and non-strategizers [t(6)=1.8, ns]. Together, this suggests that there are clear individual differences in participants’ performance. Specifically, strategizers consistently select non-homonymous alternatives independent of context and non-strategizers consistently select alternatives at a chance rate across both contexts. We use these subgroups identified by the behavioral data in the BOLD fMRI analyses below in order to determine the neural mechanisms that support the use of context when resolving a homonym’s meaning.

*Neuroimaging Results*

To evaluate the neural mechanisms that support the completion of sentences with either a homonym or an alternative, we first examined the regions of activation within the dominant and subordinate contexts relative to the hemodynamic response in the entire group. As summarized in Table 3 and Figure 2, both contexts revealed similar patterns of activation, including recruitment of left IFC and left ventral and posterolateral temporal cortex.

To evaluate the relative contribution of neural mechanisms that support the role of context in interpreting homonyms we directly contrasted the dominant and subordinate contexts in the entire group. The dominant minus subordinate contrast did not reveal any significant differences. By comparison, as summarized in Table 4 and Figure 3(A), the subordinate minus dominant contrast revealed significantly greater activation of OFC, DLPFC, inferior parietal cortex, and angular gyrus.

Since the behavioral results demonstrated evidence that a specific subgroup of participants strategically selected non-homonymous alternative words more than chance we further evaluated the relative recruitment of these regions within the subordinate context compared to the dominant context in this subgroup. We did not evaluate relative recruitment of these regions in the non-strategizer subgroup because they are a potentially heterogeneous group and we do not have any a priori predictions about how these individuals may be performing the task. To accomplish this, we extracted the significant peak voxels from the subordinate minus dominant context (see Table 4) and created a 5mm radius sphere around each peak using the MarsBar Toolbox (Brett et al., 2002) implemented in SPM5. We then calculated the percent signal change using MarsBar in each region across the time series for the dominant context and the subordinate context. We used a paired-samples t-test to compare percent signal change in each ROI in the subordinate context relative to the dominant context for each subgroup of participants and report results that survive a Bonferroni correction for multiple comparisons (p<0.013). As summarized in Figure 3(B), this analysis revealed that strategizers recruit all four regions significantly more in the subordinate context than in the dominant context: OFC [t(9)=3.76, p<0.005], DLPFC [t(9)=4.34, p<0.002], inferior parietal [t(9)=3.49, p<0.01], and angular gyrus [t(9)=3.71, p<0.005].

**General Discussion**

The current study investigated the neural mechanisms that support the process of using context to resolve a homonym’s meaning during sentence comprehension. A whole brain analysis demonstrated that, as a group, readers recruit neuroanatomic regions previously implicated in homonym comprehension, including posterolateral temporal and IFC. However, the behavioral results established evidence that there were individual differences in performance during the homonmym comprehension task. One group, which we call “strategizers,” completed sentences with single-meaning alternatives significantly more often than homophones across two linguistic contexts. We argue that this group appreciated both potential meanings of the homonym. Moreover, individuals in the strategizer subgroup upregulated DLPFC, OFC and parietal cortex to support the increased demands associated with homonym processing in the subordinate context compared to the dominant context. We associate these demands with strategic decision-making resources associated with interpreting a homonym’s meaning. We discuss the contribution of each of these regions below.

*Posterolateral temporal cortex*

In both sentence contexts, we observed activation of posterolateral temporal cortex. The observation of posterolateral temporal activation is consistent with previous investigations of the comprehension of homonyms (Rodd et al., 2005b; Gennari et al., 2007) and sentences (Ni et al., 2000; Friederici et al., 2003; Humphries et al., 2006). According to one perspective, this region plays a key role in the interpretation of word meaning (Hickok and Poeppel, 2007). Another view argues that posterolateral temporal cortex is a multimodal integration area that contributes to the organization of conceptual information underlying lexical representations of concepts and propositions (Grossman et al., 2007). A third approach asserts that posterolateral temporal cortex is specifically implicated in lexical selection rather than conceptual processing per se (Indefrey and Levelt, 2004; Kemeny et al., 2006). Regardless of the specific role that posterolateral temporal cortex plays in lexical semantic processing, our observation of increased activation in this region in all contexts may be related to upregulation of a portion of the core language processing network that helps establish word meaning.

*Inferior frontal cortex (IFC)*

Readers recruited IFC in both homonym contexts and recruitment of this region has previously been reported in other investigations on homonym comprehension (Rodd et al., 2005a; Mason and Just, 2007; Zempleni et al., 2007a; Bedny et al., 2008; Grindrod et al., 2008a; Whitney et al., 2009). IFC may play a role in the process of selecting one item from among several available alternatives (Botvinick et al., 1999; Carter et al., 2000), and IFC may specifically be involved in selecting among semantic alternatives (Thompson-Schill et al., 1997b; Wagner et al., 2001; Badre et al., 2005; Grindrod et al., 2008b; Bilenko et al., 2009). Since our experimental task requires participants to make a response selection between a homonym and an unambiguous alternative that shares one of the meanings of the homonym, our observed pattern of activation is consistent with the claims that these regions support response selection. Critically, however, our direct subtraction of subordinate minus dominant context did not reveal recruitment of IFC. This finding is not consistent with previous studies demonstrating greater IFC recruitment for a subordinate relative to a dominant context.

*Dorsolateral prefrontal cortex (DLPFC)*

We observed that DLPFC was recruited for the subordinate compared to dominant context and that individuals who appreciated both homonym meanings recruited DLPFC more than those who did not. DLPFC activation is perhaps most commonly reported in studies of strategic processing required to select among multiple alternative outcomes on decision-making tasks involving Stroop-like conflict (Cohen et al., 2000; MacDonald et al., 2000) and selecting a target from pairs of geometric shapes displaying many features (Badre and D'Esposito, 2007; Badre et al., 2009). Previous investigations evaluating probability have suggested that increased DLPFC activation on tasks such as these may be due in part to evaluating the probabilistic demands associated with a task (Casey et al., 2001; Huettel et al., 2005; Miller et al., 2005). Activation of DLPFC is rare in studies of language processing. In previous work assessing the processing of a temporary structural ambiguity in a sentence, DLPFC activation was seen during the evaluation of sentences where the main verb was embedded in a sentence structure with which it is less frequently associated compared to a sentence structure with which it is more frequently associated (Novais-Santos et al., 2007a). Our observation of increased DLPFC activation in the subordinate context relative to the dominant context in the present report is consistent with this account – the subordinate context requires individuals to evaluate a homonym for its less probable meaning, while in the dominant context participants have little need to access a less-probable meaning.

DLPFC activation also has been reported to support task difficulty and working memory (Braver et al., 1997; Cohen et al., 1997). However, we argue that such an account cannot fully explain our observation of selective recruitment of DLPFC. All materials were grammatically simple, short sentences consisting of familiar words, the stimuli were presented visually on the screen, and these stimuli were available throughout the duration of a trial in order to minimize working memory resources required for task performance. It is also unlikely that the subordinate context was simply “harder” than the dominant context in some non-specific sense since length and lexical frequency of materials were carefully matched across contexts. Additional work is needed to evaluate the precise contribution of DLPFC during language processing.

*Orbital frontal cortex (OFC)*

In the subordinate compared to dominant context we also observed OFC activation and this activation was also greater in the subgroup of strategizers compared to non-strategizers. OFC activation is often associated with inhibitory control (Horn et al., 2003) and task-switching (Braver et al., 2003). Both experimental contexts involved inhibiting one of two forced-choice responses and we observed OFC activation in both contexts. It is unlikely that OFC is activated simply to inhibit activation of the dominant meaning of a homonym since OFC also was recruited in the dominant condition, albeit less so than in the subordinate condition. Likewise, both contexts may require switching between choices. Since we observed greater recruitment of OFC in the subordinate context, it is not clear how inhibitory control or task-switching accounts would fully explain this pattern of relatively greater OFC activation for a specific context.

An alternative interpretation of OFC activation is that this region has often been implicated as supporting the calculation of risk during decision-making (Bechara et al., 1994; Rolls, 2000; Breiter et al., 2001; Salmon et al., 2003; Fiddick et al., 2005), but this interpretation has rarely been applied to models of language processing. In a context consistent with a subordinate meaning, the interpretation of a homonym is risky since it has a higher likelihood of being misunderstood than when the homonym is embedded in a sentence context consistent with its dominant meaning. For example, there is a risk in a subordinate context that the use of the word PEN will be associated with its dominant meaning (writing instrument) rather than the intended but less frequently associated meaning (animal cage), while in a dominant context it is highly likely that PEN will be associated with its more frequent meaning (writing instrument). While some human and primate work associates OFC with a relative assessment of value (Tremblay and Schultz, 1999; Elliott et al., 2008), other studies suggest that OFC plays a particular role in the evaluation of a negative consequence following from a decision (O'Doherty et al., 2001; Yacubian et al., 2006; Wheeler and Fellows, 2008).

*Inferior parietal cortex*

Inferior parietal cortex was also activated in the comparison of the subordinate relative to the dominant context. Inferior parietal cortex has been reported in other homonym comprehension tasks (Bedny et al., 2008; Grindrod et al., 2008a; Hoenig and Scheef, 2009) and sentence comprehension tasks in general (Almor et al., 2007; Novais-Santos et al., 2007b). However, the contribution of inferior parietal cortex for language processing is not well understood. Others have proposed that it supports the inhibition of a semantic meaning (Hoenig and Scheef, 2009), it is upregulated to support increased working memory demands associated with resolving ambiguity (Novais-Santos et al., 2007b), or that it integrates multiple sources of linguistic information (Almor et al., 2007). In the following section we propose a novel account for inferior parietal cortex as a component of a large-scale network that supports homonym comprehension.

*A fronto-parietal network*

Together, DLPFC, OFC, and inferior parietal cortex contribute to the resolution of a homonym’s meaning. Studies on decision-making have implicated these regions as contributing to a large-scale network that supports the calculation of expected utility when making a decision. Expected utility (EU) is generally defined as the probability of an event (P) times the value of an outcome (V), where value is equal to cost (C) minus risk (R), or EU = P \* (C - R). A recent linguistic model proposed that individuals use expected utility to make linguistic choices that maximize communicative clarity (Clark and Parikh, 2007; Clark, in press). According to this account, “probability” would refer to the likelihood of a homonym meaning in a specific context and would be supported by a probabilistic neural mechanism such as DLPFC. “Value” would refer to the difference between the working memory and attentional resource “costs” required to evaluate an alternative word (e.g., considering an alternative meaning of “pen” in a dominant context may not be worthwhile) and would be supported by value mechanism such as OFC. Lastly, expected utility would require the integration of probabilistic information about a homonym’s meaning and value information and would be supported by a neural mechanism known to contribute to integration. Previous neuroimaging studies have demonstrated that inferior parietal cortex contributes to integrating the probability and risk components of a decision into a single currency such as expected, or physiological, utility (Platt and Glimcher, 1999; Paulus et al., 2001; Huettel et al., 2005).

The observation that there are individual differences in the performance of two subgroups of participants requires some additional investigation to determine why some individuals interpret homonyms differently than other individuals. Individuals who decided to complete a sentence with a non-homonymous word also showed greater recruitment of a frontal-parietal decision-making network in a subordinate context compared to a dominant context. One potential account for these different behavioral performance patterns is that it has long been established that individuals widely vary along a continuum of risk-aversive and risk-taking behavior. In the context of our proposed decision-making model, it is possible that strategizers are relatively risk averse and therefore complete sentences so they are more likely to be understood. Other potential accounts include the possibilities that strategizers had increased word knowledge of the homonyms and therefore were more likely to appreciate the subordinate meaning, or that the strategizers had greater working memory resources and were therefore more able to select an alternative. It is unfortunate that we did not assess these characteristics in the individuals participating in the present study, and an important direction for future empirical enquiry will evaluate how individual differences in risky behavior, word knowledge, and working memory account for some individual differences in lexical processing. Additionally, it is necessary to evaluate why the non-strategizers did not differentiate between homonyms and alternatives or between sentence contexts. By accounting for individual differences such as these, researchers may be able to resolve conflicting psycholinguistic findings, such as those demonstrating that individuals do strategically use communication (Haywood et al., 2005) and those that do not (Ferreira, 2008).

A potential limitation of the current study is concerned with the relatively small number of stimuli involving selection of a homonym or a unique alternative in each context. The neuroanatomic regions recruited during the selection of a homonym response may differ from those regions recruited when participants selected an unambiguous alternative response, and this may have confounded our assessment of strategic decision-making in language. For example, it has been demonstrated that activation of brain regions associated with making a financial decision in a non-linguistic “shopping” task can be used to predict a participant’s response (Knutson et al., 2007). We were unable to perform a similar analysis in the current study because the limited statistical power associated with the outcome of such an analysis in our dataset would render the results difficult to interpret. The small number of stimuli also prevented us from determining the extent to which participants “activated” the dominant or subordinate meaning of each homonym. Finally, the limited amount of available time for collecting additional data prevented us from determining the component of the decision-making model that has the greatest impact on the activation pattern, namely, maximizing the likelihood of being understood, minimizing the risk associated with misinterpretation, or both. Future research that evaluates the different neural responses associated with a specific linguistic choice with a larger sampling of stimuli will allow us to have enough data to help constrain our proposed model of strategic decision-making for language in a more informed manner.

With these caveats in mind, we found that a subset of individuals strategically completed sentences with non-homonymous words that were otherwise likely to be misinterpreted. Furthermore, we demonstrated that the neural basis for this process does not appear to depend exclusively on an automatic mechanism that resolves semantic competition in IFC. Instead, our observations are consistent with an account that proposes that proposes strategic decision-making resources situated in a frontal-parietal network contribute to using context in order to resolve a homonym’s meaning. These findings highlight the importance for integrating strategic decision-making resources into models of language processing.

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Table 1

Example stimulus materials for the homonym “pen” in the Dominant and the Subordinate contexts

|  |  |  |
| --- | --- | --- |
| **Alternative Choice** | quill | cage |
| **Homonym Choice** | pen | pen |
| **Completion Sentence** | She needed a \_\_\_. | She needed a \_\_\_. |
| **Context Sentence** | Kim had some ink. | Kim had some pigs. |
| **Context** | Dominant | Subordinate |

Table 2

Mean rate of alternative choices (%) and standard error for responses in the Dominant and Subordinate contexts.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Group** | **N** | **Dominant** | | | **Subordinate** | | |
|  |  | Mean (SE) | Low | High | Mean (SE) | Low | High |
| Total | 17 | 68.93 (4.1) | 33 | 100 | 73.16 (3.6) | 37 | 94 |
|  |  |  |  |  |  |  |  |
| Strategizers | 10 | 79.16 (2.5) | 33 | 69 | 79.16 (3.4) | 33 | 83 |
| Non-strategizers | 7 | 54.32 (5.9) | 71 | 100 | 64.57 (6.2) | 63 | 94 |

Table 3

Neuroanatomic regions of activation and Talairach coordinates for the Dominant Context and Subordinate Context relative to Resting Baseline

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Neuroanatomic Region (BA)** | **L/R** | **Coordinates** | | | **Voxels** | **Z-score** |
| **Dominant Context** | | | | | | |
| Inferior frontal cortex (44) | L | -38 | 9 | 27 | 448 | 5.65 |
| Ventral temporal (22/21) | L | -48 | -44 | 8 | 197 | 5.33 |
| Middle occipital (19) | L | -26 | -62 | 40 | 26 | 4.68 |
| Superior temporal (37) | L | -40 | -45 | -13 | 354 | 5.81 |
| Posterior occipital cortex (18) | L | -24 | -84 | -3 | 654 | 6.37 |
| Posterior occipital cortex (18) | R | -24 | -85 | 1 | 389 | 5.43 |
| Orbital frontal cortex (47) | L | -44 | 27 | -10 | 64 | 5.03 |
| Dorsal inferior frontal (6) | L | -40 | 1 | 55 | 22 | 4.59 |
| **Subordinate Context** | | | | | | |
| Inferior frontal cortex (44) | L | -38 | 9 | 27 | 770 | 5.54 |
| Anterior cingulate (32) | -- | -6 | 16 | 39 | 56 | 5.08 |
| Angular gyrus (39) | R | 32 | -67 | 27 | 100 | 5.46 |
| Ventral temporal (21/37) | L | -46 | -46 | 8 | 215 | 5.35 |
| Posterior occipital cortex (18) | L | -24 | -84 | 3 | 1206 | 6.26 |
| Posterior occipital cortex (18) | R | 30 | -76 | -1 | 761 | 5.83 |
| Middle occipital (19) | L | -26 | -60 | 38 | 93 | 5.14 |
| Orbital frontal cortex (47) | L | -40 | 29 | -8 | 112 | 5.01 |
| Middle occipital (19) |  | 32 | -79 | 18 | 23 | 4.95 |

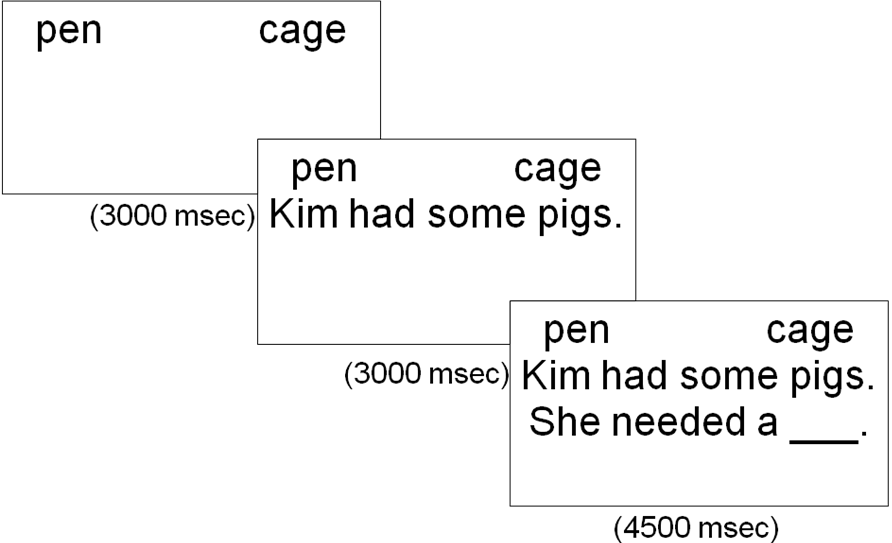
Table 4

Neuroanatomic regions of activation and Talairach coordinates for the direct subtraction of Subordinate minus Dominant context for all participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Neuroanatomic Region (BA)** | **L/R** | **Coordinates** | | | **Voxels** | **Z-score** |
| **Subordinate > Dominant Context** | | | | | | |
| Dorsolateral prefrontal (9) | L | -44 | 27 | 34 | 43 | 4.16 |
| Orbital frontal (11) | L | -46 | 44 | -14 | 65 | 4.10 |
| Inferior parietal (40) | L | -42 | -64 | 46 | 455 | 4.02 |
| Angular gyrus (39) | L | -32 | -67 | 25 | 108 | 3.96 |

Figure 1

An illustration of a typical experimental trial: Event 1 we presented two choices (a homonym and unambiguous alternative), Event 2 we presented a context sentence, Event 3 we presented a carrier sentence.

Figure 2

Regions of BOLD activation for the Dominant (A) and Subordinate (B) contexts relative to the hemodynamic response.

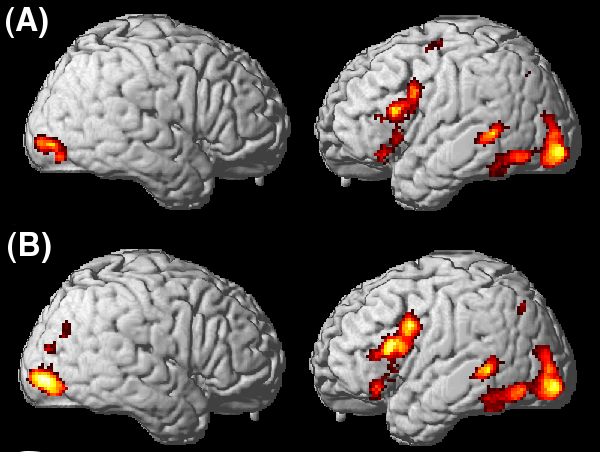


Figure 3

Regions of BOLD activation for all participants for the Subordinate minus Dominant context (A) and the mean percent signal change for regions observed in Subordinate minus Dominant contrast for the “strategizer” subgroup of participants who preferred alternative responses (B).

