How the brain responds to any: An MEG study

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1. Introduction

The word any is referred to as a negative polarity item (NPI), because any is typically tolerated in sentences that contain negative expressions such as nobody, none, never, is unlikely to, regrets that, and denies. In striking contrast, it is not tolerated in sentences with the positive counterparts of these expressions – everybody, some, always, is likely to, is pleased that and admits. Examples illustrating the differences are given in (1a) and (2a), where the symbol ‘‘’’ indicates that the sentences in (2) are semantically deviant. The deviance in the sentences in (2) is clearly due to the presence of any in these sentences. If the word some is used instead of any, all of the sentences in (2) become acceptable.

(1) a. John did not eat any of the cake.
   b. Nobody ate any of the cake.
   c. John never eats any cake.
   d. John denies eating any of the cake.

(2) a. ‘John ate any of the cake.
   b. ‘Everybody ate any of the cake.
   c. ‘John always eats any of the cake.
   d. ‘John admits eating any of the cake.

Current linguistic accounts contend that the acceptability of NPIs such as any is the result of a complex interaction between the meanings of these expressions, and certain syntactic and semantic constraints on where they may occur (Chierchia, 2004, 2006; Kadmon & Landman, 1993; Krifka, 1995). A syntactic constraint on the licensing of negative polarity items is that expressions like any must be in a specific structural relation (known as c-command) with another expression, called its licensor. In the examples in (1), the licensors of the NPI any are the words nobody, never, denies and not. There is also a semantic constraint on the acceptability of expressions like any. The semantic constraint maintains that the licensor must be downward entailing. Downward entailing (DE) expressions are ones that validate inferences from general terms to specific terms. So, for example, nobody is downward entailing. This is shown by the validity of the inference from the general statement in with the general term fruit in (3a) to the statement with the specific term bananas in (4a). The examples (3b) and (4b) show that the same inference is not valid if the non-downward entailing expressions everybody is substituted for nobody. It could be true that everybody ate fruit, whereas nobody ate bananas.

(3) a. Nobody ate fruit.
   b. Everybody ate fruit.

(4) a. Nobody ate bananas.
   b. Everybody ate bananas.

When the semantic requirement (of a downward entailing licensor) is not met, the result is an unacceptable statement, as illustrated in (2).

Our evident ability to quickly and easily gauge the acceptability and unacceptability of such minimal pairs of sentences hints at the existence of linguistic processes organized to achieve a rapid, automatic, and conclusive judgment about the contextual
appropriateness of an NPI, such as English *any*. Indeed, evidence from studies using event-related potential (ERP) measurements suggests that specific brain responses are elicited by acceptable versus anomalous sentences that contain NPIs.

In a number of studies, violations of the licensing of NPIs have been reported to elicit a P600 response, a positive ERP over medial parietal regions at a latency of 500–1000 ms after the onset of the NPI (Drenhaus, beim Graben, Sadd, & Frisch, 2006; Shao & Neville, 1998; Steinhaus, Drury, Portner, Walenski, & Ullman, 2010; Xiang, Dillon, & Phillips, 2009). The P600 has generally been interpreted as an indication of reanalysis and repair processes that are induced following the detection of a mistaken decision that was made earlier in language processing. The P600 response was found in studies involving the detection of morphosyntactic violations (e.g. *Mary were writing a letter*; Friederici, Pfeifer, & Hahne, 1993; Hagoort, Brown, & Groothusen, 1993) as well as in response to violations of the semantic selectional restrictions on the kinds of nouns that can be associated with verbs (e.g. *The rock was thinking of Vienna*; Osterhout, Holcomb, & Swinney, 1994).

Although it has been well attested that the presence of an unlicensed NPI results in a P600, the language-internal processes that are involved in the detection and possible realanalysis of illicit NPIs are not entirely clear. Earlier latency ERP effects have also been found with NPI-licensing violations, although the results are not consistent. For instance, Shao and Neville (1998) found an early left anterior negativity (LAN) in fronto-anterior temporal areas for sentences that contained one of three different NPIs (*ever, any, and yet*) but lacked a suitable licensor (e.g. *Max says that he has ever been to a birthday*). On the other hand, an ERP study of German NPIs by Sadd, Drenhaus, and Frisch (2004), and a follow-up study by Drenhaus, beim Graben, Sadd, and Frisch (2006) found only an N400 response to the unlicensed German NPI *jemals* (*ever*). These conflicting findings are all the more puzzling because these different kinds of ERP responses are usually thought to be indications of independent linguistic mechanisms: LAN responses are typically associated with morphosyntactic violations, whereas N400 effects are typically linked to problems involving integration of lexical items with unanticipated semantic or pragmatic content.

The present study is, to our knowledge, the first investigation of brain responses to the NPI *any* in licensed versus unlicensed contexts using magnetoencephalography (MEG). Our study of healthy adult subjects had two major objectives. First, we wished to determine if we could elicit differential brain responses to the two NPI licensing conditions in an experimental paradigm that did not require any explicit judgments about the acceptability of the sentences. This goal was predicated by our plans for future developmental studies. Since young children are not capable of making metalinguistic judgments, we employed instead an orthogonal task requiring subjects to detect a target (the word “cheese”) in distractor sentences. This experiment is the first to use MEG to replicate previous electrophysiological results. Therefore, we chose to follow previous studies in presenting materials visually, so as to avoid any potential confounds that could be introduced by changing to auditory presentation. Our second goal was to extend our understanding of the brain responses to licensed and unlicensed NPIs by localizing brain generators of MEG responses with a tomographic imaging method (LORETA). The study focused on a single negative polarity item: *any*, and the licensing context was limited to the minimal pair involving the quantificational expressions minimal pair: *nobody vs. everybody*.

2. Results

Upon visual examination of the MEG sensor activity and the surface distribution of the magnetic flux, we observed that the maximum activity was distributed over large portions of the left and right temporal areas, with major deflections starting at 300 ms and continuing until the end of the epoch. A clear evoked response emerged when a single sensor was selected: a biphasic response to the unlicensed condition was evident in one of the left posterior temporal sensors as shown in Fig. 1.

We focused our analysis on six bilateral regions of interest (ROIs) identified in previous fMRI and MEG studies of semantic and syntactic processing (Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Humphries, Binder, Medler, & Liebenthal, 2006, 2007; Rogalsky & Hickok, 2009) (see Table 1 for Talairach coordinates and labels). These included the posterior areas of the superior and middle temporal lobe, supramarginal area, anterior and posterior inferior frontal lobe, and the anterior temporal pole. Fig. 2 shows the ROI activation waveforms for significant ROIs.

2.1. Regions with greater activation in the licensed condition

The pST showed bilateral differences in activity from 100 to 300 ms. Two time ranges were identified in the left hemisphere. The first time range was from 170 to 200 ms, showing significantly larger activations for the licensed condition. The next time range also showed significantly larger responses for the licensed condition from 210 to 280 ms. In addition, a significant time range for the right pST was detected from 130 to 160 ms for the licensed condition.

Two other ROIs showed a larger effect for the correct condition: the right anterior ST and the left pMT. For the right aST, we identified two significant time ranges. The ROI activity was significantly larger for licensed *any* from 110 to 150 ms, and from 420 to 470 ms. No significant differences were found for the left aST. From 250 to 280 ms, the response for the licensed condition was larger in the left pMT.

2.2. Regions with greater activation in the unlicensed condition

The supramarginal area (superior to the primary auditory cortex) showed significant differences in two time ranges in the left hemisphere. In the left hemisphere, the first significant time
The unlicensed condition resulted in larger activations during this time window. A second significant time range was identified in the left supramarginal area during the P600 time latency. The differences in this area were evident from 590 to 620 ms after onset. During this time range, the unlicensed condition was significantly larger. Latency-wise, this result replicates the outcome of ERP studies that reported a P600 response to unlicensed NPIs. In addition, the supramarginal gyrus is one of the areas identified as a generator of the P600 in MEG studies of syntactic violations (e.g., Kwon et al., 2005; Service, Helenius, Maury, & Salmelin, 2007).

The posterior MT region showed amplitude effects in three time windows lateralized to the left hemisphere. No such differences were evident for the right pMT. From 460 to 490 ms, the unlicensed condition showed larger amplitudes. The latency of this component occurred during the N400/LAN time range and started 50 ms after the component found in the left SG region. In addition, from 630 to 660 ms, the ROI activity was significantly larger for the unlicensed condition. This later response started at 630 ms partially overlapping with the timing of the P600-like response, which was found in the SG starting at 590 ms.

No significant effects were identified in the inferior frontal areas or in the right supramarginal gyrus.

### Table 1
Locations for the ROI in Talairach space.

<table>
<thead>
<tr>
<th>Center of region of interest</th>
<th>Brodmann area label</th>
<th>Left hemisphere Talairach coordinates (mm)</th>
<th>Right hemisphere Talairach coordinates (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior superior temporal</td>
<td>BA22</td>
<td>-53, -41, 10</td>
<td>53, -41, 9</td>
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<tr>
<td>Posterior middle temporal area</td>
<td>BA39</td>
<td>-43, -65,20</td>
<td>44, -65, 21</td>
</tr>
<tr>
<td>Supramarginal</td>
<td>BA40</td>
<td>-50, -44, 29</td>
<td>51, -45, 29</td>
</tr>
<tr>
<td>Anterior superior temporal area</td>
<td>BA38</td>
<td>-38, 10, -24</td>
<td>38, 10, -24</td>
</tr>
<tr>
<td>Posterior inferior frontal area</td>
<td>BA44</td>
<td>-50, 8, 14</td>
<td>51, 9, 13</td>
</tr>
<tr>
<td>Anterior inferior frontal area</td>
<td>BA45</td>
<td>-49, 22, 9</td>
<td>48, 21, 9</td>
</tr>
</tbody>
</table>

3. Discussion

The present study used MEG to study the timing and location of brain regions involved in the processing of negative polarity items in the absence of directed attention to the grammatical status of the items in question. We analyzed the activity of a bilateral temporo-frontal network that included the parietal areas (supramarginal area), posterior middle temporal areas, anterior and posterior superior temporal areas and anterior and posterior inferior frontal areas as potential loci for the processes invoked for NPI licensing. These areas have been linked to semantic integration effects and syntactic processing in several MEG and fMRI studies (Humphries et al., 2007; Rogalsky & Hickok, 2009; Friederici et al., 2003; Halgren et al., 2002; Helenius, Salmelin, Service, & Connolly, 1998; Kwon et al., 2005; Maess, Herrmann, Hahne, Nakamura, & Friederici, 2006; Raettig, Frisch, Friederici, & Kotz, 2010; Service et al., 2007). Our main results confirm and extend previous ERP studies on NPIs (Drenhaus et al., 2006; Steinhauer et al., 2010; Shao & Neville 1998; Saddy et al., 2004): Responses obtained in the unlicensed condition were significantly larger in the left tempo-parietal areas during the N400/LAN time window (400–500 ms) followed by a second evoked response in the time domain of the P600. An early response, larger for the licensed
condition was elicited with a more anterior distribution than for the later responses.

3.1. Responses to the licensed condition

We found differences between 130 and 280 ms after the onset of the NPI, with larger activations elicited by the licensed NPI in the left and right pST and right aST. The latency of this initial response coincides with the left frontal negativity effect (N280) found by Neville, Mills, and Lawson (1992) for closed-class items. Neville’s study compared the patterns of activation of closed and open class words in a sentence reading task and found that the N280 effect for function words was independent of word length and frequency. The pattern for open-class words was similar, except that the initial negativity peaked at 350 ms (N350). The study concluded that the N280 reflects the initiation of word identification processes and contextual integration processes. Localization studies place lexical access processes and combinatorial semantics to similar areas to those identified in the current study. In particular, MEG studies localized lexical access processes to the middle and posterior portions of the STG for content words (e.g. Service et al., 2007) and for function words (Halgren et al., 2002). Moreover, these areas are sensitive to the amount of lexical information that needs to be accessed. Some fMRI studies (Humphries et al., 2007) found that semantically congruent word lists generated larger activations than pseudo-word or unrelated word lists in the left STS/MTG. To sum up, temporal activity that develops during the first 300 ms has been suggested to reflect word access processes, which are initiated faster for function words, as compared to open-class words.

Although this initial activation in the temporal areas may be related to lexical access, the direction of the effect we found is not straightforward to interpret. Generally, the detection of a word category violation elicits an early ERP response, which has been associated with word category violations (e.g. Max’s of…). However, at a very local level, the word category of the NPI matches the selection restrictions of the preceding verb in both contexts.

It could be the case that the effect is a spill-over effect of the preceding context. Although the sentences were constructed as minimal pairs, the embedded sentence in which the NPI was positioned began with different words. Because we did not control for the effects of these different words, at this point we are not in a position to make any conclusive inferences regarding the initial response that was evoked for the target items in the licensed condition.

3.2. 400–500 ms latency responses

Our ROI analysis revealed a significant difference between 400 and 500 ms for the unlicensed condition. The presence of the NPI any in a context where there is no downward-entailing licensor modulates the responses of the supramarginal area and middle temporal regions. The SG shows a peak in activity between 410 and 440 ms and 50 ms later, the activity becomes significantly different in the pMT area. The latency of the component(s) coincided with the NPI-evoked responses found in the ERP studies by Shao and Neville (1998) and by Saddy et al. (2004).

One of the current leading accounts of NPI (Chierchia, 2004) argues that the licensing of NPIs draws upon syntactic, semantic and pragmatic knowledge. Syntactically, the NPI must be in the c-commanding domain of a licensor. Semantically, the NPI must agree in features with a downward-entailing expression. Pragmatically, a statement containing an NPI must be more informative than the corresponding statement containing an existential indefinite (e.g. some). Under the scope of negative licensors such as nobody and never, for example, all of these conditions are met. Adopting this theoretical perspective, the elicited 400-ms response for the unlicensed condition leads us to the hypothesis that the 400-ms response reflects a conflict in the resolution of the semantic and syntactic requirements of NPI licensing. That is to say, the elicitation of the 400-ms response could be seen as a failure of semantic integration when no matching DE licensor in the preceding context is found. The first response found at 410 ms in the pST ROI could correspond to the parser attempts to find any agreeing licensors (as described in Shao & Neville (1998)) while the second response found at 440 ms in the SG ROI would correspond to the failure to semantically integrate the NPI (as argued in Saddy et al., 2004 and Drenhaus, 2006).

Moreover, numerous studies support the idea that semantic and syntactic processes modulate the activation of the SG and pSTG. The ROIs under discussion have been identified in studies of semantic integration processes using MEG (e.g. Halgren et al., 2002; Helenius et al., 1998) as well as fMRI (Friederici et al., 2003; Ni et al., 2000). Studies that focused on morpho-syntactic processes (including phrase structure violations, case agreement violations, etc.) also have indicated the involvement of these areas (e.g. Friederici et al., 2003; Service et al., 2007).

3.3. The 600-ms response

Activity in the 400-ms range elicited by unlicensed any was followed by a second wave of activity in the same time window as the P600. Once again, we observed a peak in activity in the 600 ms range in two different areas. The earliest response was in the pST ROI between 590 and 620 ms, followed by another significant response in then the SG ROI between 630 and 660 ms. The latency range of this components are consistent with the NPI-evoked P600 response elicited in almost every ERP study we reviewed (Drenhaus et al., 2006; Steinhauser et al., 2010; Xiang et al., 2009).

The spatially distributed pattern in the 600 ms range is consistent with the grammatical account of NPI licensing. Following our interpretation of the 400–ms response to reflect the detection of a morphological mismatch, it is possible that the initial 600-ms response in the pST ROI is the manifestation of reanalysis/repar processes (Friederici et al., 2003). The P600 effect has been evoked by different types syntactic anomalies including morphosyntactic violations. For instance, Gunter, Friederici, and Schriefers (2000) found a P600 (as well as a LAN) following syntactic gender violations (see also Hagoort et al. (1993) and Friederici et al. (1993) for discussion). Spatially, P600 effects have been located in the perisylvian areas, close to the SG (e.g. Kwon et al., 2005; Service et al., 2007).

Studies on NPI processing have raised a second interpretation for the P600 effect found for unlicensed conditions. Although the P600 is generally considered the consequence of repair and reanalysis processes, in the context of NPI processing, the P600 can be viewed as an effect of error detection of global semantic processes that compute sentence-level truth conditions and logical inferences (e.g. Drenhaus et al., 2006; Steinhauser et al., 2010; Xiang et al., 2009). In correspondence with our ROI analysis, a few fMRI studies of sentence-level processing (e.g. Humphries et al., 2007) suggested that the posterior areas of the temporal lobe (superior temporal lobe and medial temporal lobe) may be involved in processes that integrate the unfolding semantic and syntactic representations into complete and coherent propositions. This view of the P600 effect raises the possibility that the second response found in the left SG ROI at 630 ms is the reflection of the failure to yield the appropriate propositional content to generate a complete and coherent proposition.

To sum up, our results suggest that there are two temporally and spatially different components happening during the 600-ms range. The first component in this time range could be interpreted
as the effect of syntactic reanalysis driven by the morphosyntactic violations. The second component could reflect a conflict at a higher level of representation. The suggestion that there are two different components derives mainly from the spatial distinction that resulted from our ROI analysis. Needless to say, more extensive research is necessary to evaluate this hypothesis.

Finally, some remarks regarding the (lack of) involvement of the frontal areas. Several studies have argued that lexico-semantic incongruency and/or syntactic violations effects are driven by the inferior frontal areas (see Friederici (2002) for an overview). Considering the grammatical NPI licensing perspective assumed in this paper, we expected the IFG to be one of the sources for the P600 effects. However, our results showed no differential engagement of the IFG. Why is this area not sensitive to NPI licensing? At this stage, we can only speculate about this null result. We would suggest that this particular activity in the IFG (or rather lack of significant differences between conditions) may be due to the fact that subjects were not required to make metalinguistic judgments about the grammaticality or congruity of the sentences. Studies that have examined the effect of attention in sentence processes suggest that task demands may modulate the level of engagement of the IFG. For instance, Rogalsky and Hickock (2009) found that the activity of the IFG was not distinctive when comparing sentences to noun lists, but its activity increased when the task demanded attention to syntactic or semantic properties of the sentences. This suggests that IFG may be used for top-down processes that require more controlled access to sentential features. Since the main aim of this study was to see if we could evoke a brain response to NPIs without directing the subjects’ attention to the acceptability or unacceptability of the materials, further studies comparing the adult responses to NPI processing while modifying attention demands will be undertaken in the future to clarify the role of the IFG in sentence processing.

4. Conclusions

Integrating an NPI in a scope domain where there is no matching semantic property leads to increased activity in perisylvian areas dedicated to the integration of morpho-syntactic and semantic representations at a local and sentence level. The nature of the NPI processing under study suggests that these areas may also be involved for the mapping of a logical semantic level of representation. Our results are compatible with current linguistic approaches that resort to syntactic/semantic computations for NPI licensing. A simple distractor task to investigate the automatic processing of NPI licensing was used successfully. A spoken version of this task would be well within the cognitive capabilities of young children and can be used to study the development of NPI processing in future studies.

5. Methods

5.1. Participants

Sixteen subjects (10 females) volunteered to participate in our study. All subjects were right-handed, had normal or corrected-to-normal vision, and did not report neurological abnormalities. All procedures were approved by the Human Ethics committee of Macquarie University.

5.2. Materials

Sentences were projected onto a display screen placed at a distance of 40 cm above the subject’s head with subjects in a supine position.

A total of 240 sentences, including 120 fillers were presented. Words were presented in white letters against a black background. To simulate a more natural reading pace, each sentence was divided in seven regions (Fig. 3). The critical word any was always presented by itself, always preceded by a transitive verb and always followed by the sequence of the.

The experiment consisted of two conditions: the unlicensed condition (everybody/any) and the licensed condition (nobody/any). Each sentence was embedded under an introductory phrase such as ‘I heard that’ or ‘X told me that.’ Sixty minimal pairs were created; sentences differed in whether or not they contained the negative quantifier nobody, as in (5). The other half of the sentences contained the universal quantifier everybody, which rendered the NPI any unlicensed, as in (6). In addition to the condition sentences, 120 sentences with Quantified Noun Phrases (e.g. some, many, etc.) were presented. Fillers consisted of 70 grammatical, 30 ungrammatical sentences and 20 catch trials (i.e. sentences with the word cheese). Ungrammatical sentences contained agreement violations (e.g. several of the patience/many of the farmers likes this time of the season). The target word any did not appear in any of the filler sentences or the catch trials.

Fig. 3. Example trial showing sequence and timing of events. Each trial sentence started with an initial fixation cross, presented for 1000 ms, followed by a 1000 ms gap, before presenting the sentence itself. Each sentence region appeared centered on the fixation cross. Given the variation in the length of the words, the presentation of each region varied. Each region was followed with a 200 ms blank screen.
5. MEG measurements

Brain responses were measured in a magnetically-shielded room (Fujihara Co. Ltd., Tokyo, Japan) with a KIT whole head MEG system (Model PQ1160R-N2, KIT, Kanazawa, Japan) consisting of 160 coaxial first-order gradiometers with a 50 mm baseline (Kado et al., 1999; Uehara et al., 2003). MEG data were acquired with a sampling rate of 1000 Hz with a bandpass filter of 0.03–200 Hz and a 50 Hz notch filter.

5.4. Data analysis

MEG data were analyzed offline using BESA 5.3 (MEGIS software GmbH, Graefing, Germany) and Matlab 7.10 for statistical analysis. Before averaging, trials with artifacts with an amplitude exceeding 3500 fT were rejected. The remaining trials were averaged separately for each subject and condition over an epoch of 100 ms before the onset of the critical word and 800 ms after. No baseline correction was applied; instead, the averaged data were filtered using a high pass filter at 0.3 Hz and a low pass filter at 40 Hz. To identify neural generators of the observed surface differences, we used the distributed inverse method LORETA (Low Resolution Electromagnetic Tomography: Pascual-Marqui, Michel, & Lehmann, 1994) as implemented in BESA 5.3. LORETA is a weighted minimum norm solution, which estimates the source activity of the brain volume. The brain volume is represented by a finite number of fixed dipoles and it is assumed that neighboring dipoles are highly synchronized. This method offers a distributed source solution with no previous assumptions about their distribution.

LORETA solutions were computed on a standardized Talairach-transformed MRI image. Co-registration between standardized and individual head geometry was based on the digitized head surface points recorded prior to data acquisition. Prior to MEG recordings, MEG marker coils were placed on the subject's head and head shape was measured with a pen digitizer (Polhemus Fastrack, Colchester, VT).

The volume conductor was modeled with a sphere fitted to each individual's digitized head surface points, using an iterative least-squares fitting procedure implemented in BESA 5.3. The digitized head surface points define the center of the sphere. The volume used in the LORETA solutions was defined by 83.6% of the radius of the spherical head model. The default model included 5970 equal-sided (7 mm) voxels. Each voxel contained one regional source.

5.4.1. ROI analysis

We limited our analysis to six bilateral regions of interest (ROIs). Each of these regions consisted in a different number of the brain volume voxels selected by their Talairach labels (Lancaster et al., 1997, 2000).

5.4.2. Statistical analysis

Paired t-test comparisons across all samples were conducted to reveal significant time ranges. To obtain the temporal activation of these regions, the mean current density was calculated for every 10 ms of the original epoch, which resulted in 60 discrete solutions from 100 ms to 700 ms after onset. Each of the 60 solutions was concatenated to observe the temporal evolution of the activity in each ROI. We chose a more conservative analysis to reveal the underlying components. Rather than selecting a priori time windows that could mask components that may be revealed by using MEG and/or a distractor task, we chose a statistical–graphical method to evaluate significant intervals (Guthrie & Buchwald, 1991). Where the p values of the paired t-tests were <0.05 (autocorrelation value 0.7, N = 16) for three consecutive time points or more, the time range was considered significant (Guthrie & Buchwald, 1991). This approach did not assume any a priori hypothesis about the latency of the components.

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