

Neural activity associated with metaphor comprehension: spatial analysis

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Abstract

Though neuropsychological data indicate that the right hemisphere (RH) plays a major role in metaphor processing, other studies suggest that, at least during some phases of this processing, a RH advantage may not exist. The present study explores, through a temporally agile neural signal—the event-related potentials (ERPs)—, and through source-localization algorithms applied to ERP recordings, whether the crucial phase of metaphor comprehension presents or not a RH advantage. Participants ($n = 24$) were submitted to a S1–S2 experimental paradigm. S1 consisted of visually presented metaphoric sentences (e.g., “Green lung of the city”), followed by S2, which consisted of words that could (i.e., “Park”) or could not (i.e., “Semaphore”) be defined by S1. ERPs elicited by S2 were analyzed using temporal principal component analysis (tPCA) and source-localization algorithms. These analyses revealed that metaphorically related S2 words showed significantly higher N400 amplitudes than non-related S2 words. Source-localization algorithms showed differential activity between the two S2 conditions in the right middle/superior temporal areas. These results support the existence of an important RH contribution to (at least) one phase of metaphor processing and, furthermore, implicate the temporal cortex with respect to that contribution.

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Metaphor is a very important component of our daily verbal interaction. Although the literature contains suggestions of processing differences between metaphoric and non-metaphoric language, cognitive neuroscience has not yet systematically explored these proposed distinctions. One possible difference resides in the neural origin of metaphor comprehension: several neuropsychological studies have reported that patients with right hemisphere (RH) damage often show impaired comprehension of metaphors [4,5,18,22]. On the other hand, these patients exhibit much less or no difficulty processing non-metaphoric language. Also in line with these findings, normal subjects show a RH superiority in metaphor processing under a hemifield presentation paradigm [2].

However, neural response to metaphors is a complex process that, according to some studies, may not present a RH advantage in some phases [10]. In fact, PET-based neuroimaging data from healthy subjects show that brain response to metaphors involves several left hemisphere areas [3].

The main problem of these neuropsychological/behavioral and neuroimaging studies is their poor temporal resolution: it is impossible to discriminate based solely on them which step of the neural response to metaphors (e.g., initial sensory processing, subsequent categorization of stimuli as linguistic material, metaphor discrimination and comprehension, response decision, etc.) is right-lateralized and which one is left-lateralized or bilateral. In other words, it is impossible to determine from neuropsychological or neuroimaging data whether the critical and specific phase of metaphor comprehension presents, indeed, a RH

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advantage or, as some authors suggest, there is not such an advantage.

Given that some of the main responses to linguistic material, including semantic processing, occur within 500 ms from stimulus onset (see ref. [11] for a review), a temporally agile signal capable of detecting and distinguishing rapid and brief neural changes should be employed in order to isolate the neural activity associated with the specific phase of metaphor comprehension and to further test whether that phase is characterized by a RH advantage. Event-related potentials (ERP) are particularly well-suited for this purpose. Moreover, source-localization algorithms may be applied to ERP data in order to determine the origin of each component (i.e., of each processing phase). As explained below, healthy subjects had to decide whether a word was appropriately defined or not by a previously presented phrasal metaphor. The first scope of the present study was to detect the precise phase at which participants ‘comprehended’ that the word was (or was not) metaphorically related to the previous sentence, and to ignore other phases common to metaphoric and non-metaphoric linguistic processes. Subsequently, the right- or left-hemisphere involvement at this phase was tested.

Thirty right-handed students from the Universidad Autónoma de Madrid took part in the present experiment, though data from a final set of 24 participants were eventually analyzed, as explained later. These 24 participants (20 women), aged between 20 and 30 years (mean: 21.12; S.D.: 2.31), were all native Spanish speakers. They voluntarily took part in the experiment and provided their informed consent to participate, reporting normal or corrected-to-normal visual acuity.

The experimental procedure followed the *stimulus 1–stimulus 2* (S1–S2) experimental paradigm: each trial consisted of the presentation of two consecutive stimuli (see the complete list of stimuli at <http://www.uam.es/carretie/metaforas.htm>). ERPs were exclusively analyzed in response to S2, as explained below. S1 consisted of unfamiliar (novel) metaphoric sentences in Spanish (e.g., “*Tubo furioso que silba y aúlla*”/“Furious tube, that whistles and howls”), presented during 3000 ms. S2, presented 1800 ms after S1 offset, consisted of a Spanish word that could or could not be defined by S1 (“*Tren*”/“Train” or, alternatively, “*Lobo*”/“Wolf”) presented during 375 ms. Next S1 appeared 1000 ms after S2 onset. Twenty-eight different metaphoric sentences were employed, and they were presented twice: once followed by a highly related (metaphorically) term and once followed by a non-related term in a randomized order. Therefore, a total number of 56 S1–S2 trials was presented. Both S1 and S2 were displayed in white color over a black background. The first letter of the first word was capitalized while the rest of letters were presented in lower-case. Sentences used as S1 had between 2 and 12 words, and all subjects reported to have had time enough to read them. Words used as S2 (which were those evoking the ERPs analyzed in the present study) had between 1 and 4 syllables. (See below results of control analyses performed on the potential

effect of the number of syllables and other characteristics of S2.)

Subjects were instructed to indicate the degree of correspondence between S2 and S1, one second after S2 (i.e., “just when the next S1 appears”, in order to avoid muscular interferences in the relevant ERPs). Two alternative verbal responses were requested from participants: “high”, if they considered that S2 was metaphorically related to S1 (i.e., ‘Train’ in our example) or “low”, if they judged that there was not any metaphoric relation between S1 and S2 (‘Wolf’). These two types of S2 will be labeled ‘R’ (related) and ‘non-R’, respectively. The task of deciding whether the word is R or non-R triggers metaphor-comprehension-related neural mechanisms. A one-second response period was considered enough in the light of previous data suggesting that main components of semantic and metaphoric processing are elicited around 500 ms from stimulus onset [8,11,18,21].

Electroencephalographic (EEG) activity was recorded using an electrode cap (ElectroCap International) with tin electrodes. Electrodes corresponded to the following scalp locations: Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, P7, P3, Pz, P4, P8, POz, O1, and O2. All scalp electrodes were referenced to linked earlobes. Electrooculographic (EOG) data were recorded supra- and infraorbitally (vertical EOG) as well as from the left versus right orbital rim (horizontal EOG). Electrode impedances were always kept below 5 k Ω . A bandpass filter of 0.3–40 Hz was applied. Recordings were continuously digitized at a sampling rate of 300 Hz during the complete recording session. The continuous recording was divided into 1000 ms epochs for each trial, beginning 200 ms before S2 onset. Trials for which subjects responded either out-of-time or responded erroneously were eliminated. Visual inspection was also carried out in order to delete epochs containing eye movements or blinks. Data from six out of the thirty participants were eliminated since number of deleted trials for them (due to artifacts and/or response errors) surpassed 20% of total trials. ERP averages were categorized according to each type of stimulus (R and non-R).

Fig. 1 shows the vertex (Cz) grand average for each stimulus condition once the baseline (prestimulus recording) had been subtracted from each ERP. This grand average corresponds to a central scalp location, where present experimental effects (described later) are clearly visible.

Components explaining most ERP variance were detected and quantified through a covariance-matrix-based temporal principal component analysis (tPCA). This technique has been repeatedly recommended for these tasks, since the exclusive use of traditional visual inspection of grand averages and voltage computation may lead to several types of misinterpretation (see ref. [6] for a review on this issue and for a description of tPCA advantages). The number of components (five) extracted was based on the scree test [7]. These extracted components were subjected to varimax rotation (Fig. 2).

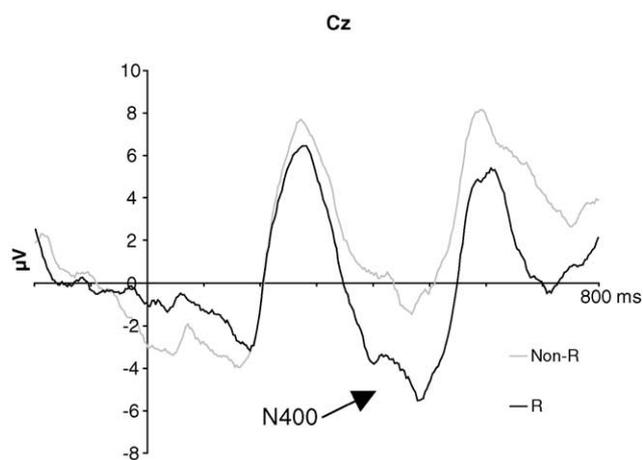


Fig. 1. Mean responses to the two types of stimuli (R: metaphorically related; non-R: non-related) at Cz.

Next, detection of any effect of the stimuli (R and non-R) on the extracted post-stimulus factors was performed. For this purpose, repeated-measures ANOVAs on factor scores were carried out. Factor scores, the parameter (resulting from the tPCA) in which factors or components are quantified, are calculated for each individual ERP, and reflect the amplitude of each component. Independent variables submitted to ANOVAs were Stimuli (two levels: R and non-R) and Recording Channels (24 levels). The effect of Stimuli alone was only significant for Factor 3 ($F(1,23) = 11.252$, $p < 0.005$). As it could be expected from visual inspection of Fig. 1, the highest amplitudes corresponded to R stimuli. Scalp topography (Fig. 3: central distribution) and temporal characteristics (i.e., peak at 406.7 ms: see Fig. 2) associate Factor 3 to the wave labeled “N400” in grand averages. This label will be employed hereafter to make results easier to understand.

The next step consisted of three-dimensionally localizing the cerebral regions that are responsible for the experimental effects on N400 (i.e., those showing greater activation in the R than in the non-R condition). Low-resolution brain electro-

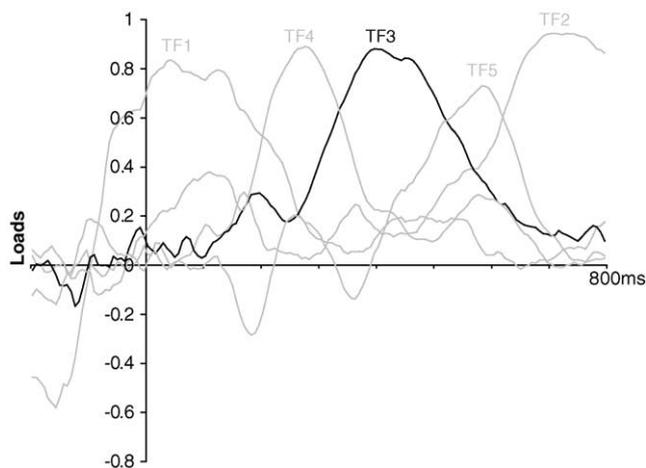


Fig. 2. tPCA: Factor loadings after varimax rotation. Temporal Factor 3 (N400), which is sensitive to the experimental effects, is drawn in black.

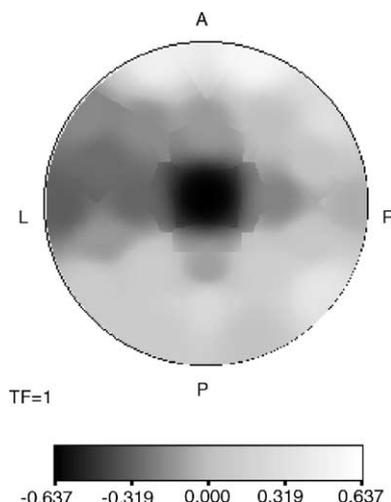


Fig. 3. Factor 3 (N400) scalp distribution. Mean factor scores (directly related to amplitudes) for each of the 24 electrode locations depicted as scalp maps (A: anterior, P: posterior, L: left, R: right).

magnetic tomography (LORETA) was applied to N400 factor scores. LORETA is a 3D, discrete linear solution for the EEG inverse problem [16]. Though, in general, solutions provided by EEG-based source-localization algorithms should be interpreted with caution due to their potential error margins, LORETA solutions have shown significant correspondence with those provided by functional magnetic resonance imaging in the same tasks [22], their error margin being modest (14 mm: [16]). In its current version, LORETA refers to a three-shell spherical model registered to the Talairach human brain atlas [20]. The solution is given, therefore, in three coordinates: ‘x’ is the distance in millimeters to the right (+) or left (–) of midline, ‘y’ is the distance anterior (+) or posterior (–) to the anterior commissure, and ‘z’ is the distance above (+) or below (–) a horizontal plane through the anterior and posterior commissures.

Thus, 48 LORETA solutions were calculated (24 subjects \times 2 conditions: R and non-R). In order to detect the region or regions responsible for the experimental effects, differences between R and non-R solutions were computed on a voxel by voxel basis. Average of these differences is shown in Fig. 4. As may be appreciated, and taking into account the error margin mentioned above, the posterior part of the right middle/superior temporal gyrus ($x = 53$, $y = -60$, $z = 15$) is the area where the R condition evoked the highest activations with respect to the non-R condition.

Three control analyses were carried out. Firstly, the fact that R and non-R stimuli actually differed in their metaphoric relationship with S1 was measured through a questionnaire. To that aim, one independent sample of 50 subjects assessed such relationship through a dimensional scale (from 1, null metaphoric relationship, to 5, maximum relationship). As supposed a priori, R stimuli were more related with S1 sentences (mean: 3.86, standard error of mean, S.E.M.: 0.05) than non-R (mean: 2.23, S.E.M.: 0.06) ($t(48) = 21.29$, $p < 0.001$). Secondly, the possible influence of frequency of

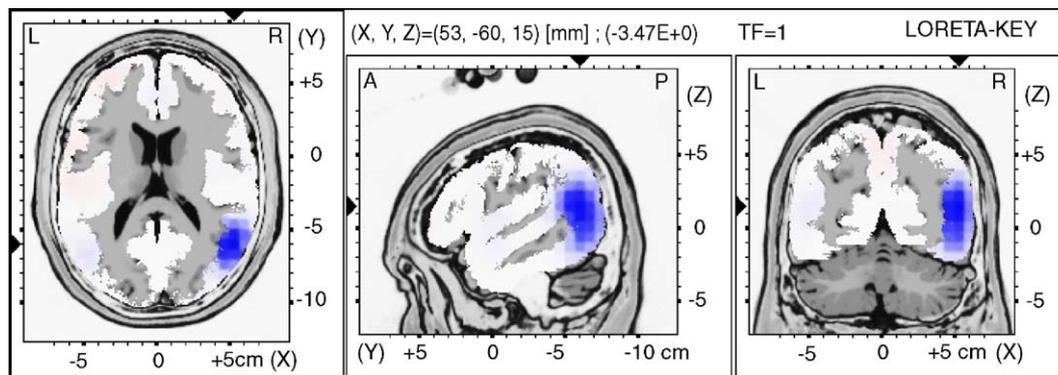


Fig. 4. Images of neural activity computed with LORETA for R (i.e., metaphorically related) minus non-R (non-related) stimuli on N400 factor scores (details in the text). Blue areas correspond to R > non-R activity, and red areas indicate R < non-R activity. Three orthogonal brain views in Talairach space, sliced through the region of maximum activity, are illustrated. Left slice: axial, seen from above, nose up; center slice: sagittal, seen from left; right slice: coronal, seen from rear. Talairach coordinates: x from left (L) to right (R); y from posterior (P) to anterior (A); z from inferior to superior.

use of R and non-R words on the observed effects was tested, since it has been reported that, at least, part of the N400 ‘behavior’ may depend on this factor [21]. Frequencies of use were extracted from ref. [1], the standard source of this information in Spanish. Differences in frequency of use of R (mean: 82.6, S.E.M.: 20.5) and non-R (mean: 45.1, S.E.M.: 9.5) words was non-significant ($t = 1.66$, $p > 0.05$). Thirdly, differences in the number of syllables between R (mean: 2.82, S.E.M.: 0.155) and non-R (mean: 2.86, S.E.M.: 0.152) words was also tested, in order to discard any influence of this variable on the observed effects. Again, differences were not significant ($t = 0.165$, $p > 0.05$).

According to present data, comprehending whether or not a concept is defined by a previously presented phrasal metaphor occurs at 400 ms. The N400 is, therefore, the reflection of a neural mechanism associated with metaphor comprehension. Semantic processing of literal linguistic stimuli is also reflected in the N400 component (see reviews on the vast N400 literature in refs. [14,15]). The fact that N400 reflects metaphoric comprehension has previously been reported [8,18]. However, these previous studies have used the ‘sentence ending’ experimental paradigm: ERPs were recorded in response to the final word of a sentence (presented word by word) which was either literal or metaphoric (e.g., “Those guys are *lions*” or “Those guys are *aggressive*”, metaphoric and literal, respectively). It is worth mentioning some authors suggest that these N400 differences in response to metaphoric versus literal endings may be due to the possibility that metaphoric endings are less predictable than literal endings are [21]. In fact, when anomalous endings are included in the study (e.g., “Those guys are *umbrellas*”), N400 shows its highest amplitudes in response to this condition [13,21]. On the contrary, the characteristics of the experimental paradigm employed in the present experiment are very different from those of tasks in which the final word in otherwise identical stimulus sentences determines the metaphoric potential of the experimental trial. The processing demands of the S1–S2 paradigm used in the present study make it highly unlikely that the

N400 component reflected primarily expectancy (anomaly) effects: non-related S2 sentences were even less expected (more anomalous) than Related S2 sentences because the non-related sentences had no relationship at all with S1.

Previous studies have not yet explored the cerebral origin of N400 associated to metaphor processing. As described in the paragraphs describing results, source-localization solutions on the N400 component showed that the right middle/superior temporal gyrus was more activated in response to R than in response to non-R stimuli. Its counterpart, the left middle/superior temporal gyrus, is activated during reading [12,17,24]. The fact that R stimuli increase the right but not the left temporal gyrus activity supports neuropsychological data mentioned in the Introduction reporting that RH damage specifically impairs the comprehension of metaphoric language [4,5,19,23]. Activation of the right middle temporal gyrus in response to metaphoric material has also been reported in PET studies on healthy subjects [3], suggesting that this area plays an important role in metaphor comprehension. Further studies employing different tasks are needed to confirm these results, since the experimental requirements seem to modulate this RH advantage [9,10].

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