

An early electrophysiological sign of semantic processing in basal extrastriate areas

MANUEL MARTÍN-LOECHES,^{a,b} JOSÉ A. HINOJOSA,^a GREGORIO GÓMEZ-JARABO,^b
AND FRANCISCO J. RUBIA^a

^aBrain Mapping Unit, Complutense University, Madrid, Spain

^bCátedra Fundación Cultural Forum de Psicobiología y Discapacidad, Departamento Psicología Biológica y de la Salud, Universidad Autónoma de Madrid, Spain

Abstract

Recognition potential (RP), a recently discovered electrophysiological response of the brain, is sensitive to semantic aspects of stimuli. Given its peak values (about 250 ms), RP may be a good candidate for the study of semantic processing during its occurrence. However, its topography and neural generators are largely unknown. To improve this state of affairs, high-resolution electroencephalography and brain electrical source analysis were carried out. Results suggest a possible origin of RP in the lingual gyrus, hence reflecting the activity of the basal extrastriate areas. RP therefore appears to be a highly valuable tool in the study of those regions considered to be the “third language areas” (in addition to Broca’s and Wernicke’s areas), whose precise role in language processing is still largely unknown. Another important finding was that RP amplitude in the left hemisphere differed as a function of the semantic category of the stimuli, providing evidence for the sensitivity of this component to semantic categorization. A tentative proposal is made with regard to the role of the basal extrastriate areas.

Descriptors: Recognition, Evoked potential, Semantic processing, Basal extrastriate areas

A recently discovered event-related potential (ERP) component, recognition potential (RP), is an electrical response of the brain that occurs when an individual views recognizable images of words (Rudell, 1991; Rudell & Hua, 1997). RP is strongly related to conscious awareness of stimuli, selective attention being an important factor for evoking RP (Rudell & Hua, 1996a). Moreover, although it has been studied mainly as a language-related ERP component, RP can also be elicited by pictures (Rudell, 1992). Stimulation procedures appear to be a crucial factor in obtaining RP, one of the best approaches being the so-called “rapid stream stimulation” (Rudell, 1992), which basically consists of presenting images at high rates, with either recognizable or nonrecognizable stimuli appearing randomly.

Rudell and Hua (1997) pointed out the possibility that RP actually reflects the semantic processing of images. We recently validated this assertion, disregarding the possibility that RP merely reflects the reaction to lower levels of word image analysis such as orthographic or letter identification, rather than semantic or conceptual analyses (Martín-Loeches, Hinojosa, Gómez-Jarabo, & Rubia, 1999). RP was shown to appear in lower levels of analysis in

the reading process, but its amplitude increased progressively as the analysis level approached the semantic, which showed the highest values. These phenomena could not be attributed to other factors such as stimulus familiarity, which have been seen to affect RP latency, but not its amplitude (Rudell & Hua, 1997).

On the other hand, RP reaches its positive peak at about 200–250 ms (Rudell, 1992), although several experimental manipulations may increase or decrease this latency (Rudell, 1991; Rudell & Hua, 1995, 1996b, 1997). Thus, the importance of RP is certainly outstanding, especially considering that the other ERP component usually related to semantic information processing has been the N400 (Kutas, 1997; Osterhout & Holcomb, 1995). The N400 is a centrally distributed negativity that appears when a semantic incongruence takes place, and can be elicited by either words or pictures (Holcomb & McPherson, 1994; Kutas, 1997; Nigam, Hoffman, & Simons, 1992). However, the N400 presents its peak amplitude at about 400 ms after stimulus onset, a time that is excessively long for reading processes (Rubin & Turano, 1992; Sereno, Rayner, & Posner, 1998). It has been proposed that the mechanism underlying the N400 would more likely reflect a relatively late post-semantic process than the semantic access process itself (Chwilla, Brown, & Hagoort, 1995; Holcomb, 1993). Accordingly, RP would be a better candidate than N400 to reflect these processes *during* their occurrence.

Recently, the possibility has been reported of finding ERP modulations sensitive to semantic aspects of stimuli within the 80–265-ms interval after stimulus onset using the “semantic differential technique” (Skrandies, 1998). RP, however, approaches such an

We thank Eva Moreno for help in data collection. We also thank A. G. Caicoya, M. Pascual, A. P. Rudell, Diane Swick, and two anonymous reviewers for highly valuable comments and help on a preliminary version of the manuscript.

Address reprint requests to: M. Martín-Loeches, Brain Mapping Unit, Pluridisciplinary Institute, Complutense University, Po. Juan XXIII, 1, 28040-Madrid, Spain. E-mail: mmartin@eucmax.sim.ucm.es.

early latency but presents the additional advantage of being a highly reliable and well-defined and studied component. Other ERP components with latencies resembling RP and also related to semantic analysis have been found over left prefrontal regions (Abdullaev & Posner, 1998; Posner & Pavese, 1998). Posner and colleagues interpreted that these regions would therefore be involved in semantic processing, that they represent the meaning of a presented word. However, this assertion may be counterintuitive to some extent, considering the large amount of evidence that suggests frontal areas subserve control, executive, or supervising functions (e.g., Fuster, 1997)—far from being an information content processing center, which appears more likely to be a function of posterior regions. It is, in fact, in posterior areas that RP appears to originate (Rudell, 1992).

However, the exact topography of this component is still largely unknown. To date, RP has been obtained mainly by means of a bipolar derivation from a pair of vertically oriented occipital electrodes, one located at around the Pz or POz position of the 10-20 International System (American Electroencephalographic Society, 1991) and the other over the Inion, other derivations yielding poorer results. Accordingly, Rudell has suggested that the RP neural generator probably lies in or near the occipital area (Rudell, 1991, 1992). Furthermore, considering that one electrode is over the Inion, RP might actually record activity originated in the basal areas. Hence, RP would be related to recent magnetoencephalographic data indicating an occipital, basal extrastriate cortex origin of neural activity specifically related to words and symbols within the 150–300-ms interval and originating in the lingual and fusiform gyri (Kuriki, Takeuchi, & Hirata, 1998; Salmelin, Service, Kiesila, Uutela, & Salonen, 1996).

If this were the case we would be in the presence of an ERP index of the activity of basal extrastriate areas. This interpretation implies important advantages. Such an ERP would allow further exploration of the role of these areas, recently discovered as language regions. Indeed, basal extrastriate areas have been called “the third language area,” to add to Broca’s and Wernicke’s areas (Kutas, 1997; Lüders et al., 1991). However, the role of these areas in language processing is still far from well known, and further research is needed. For example, they have been seen to be activated for many types of verbal information processing (phonological, orthographical, semantic) and for object identification, even when semantic information comes from the tactile modality (Büchel, Price, & Friston, 1998; Nobre, Allison, & McCarthy, 1994; Price, 1997). It is imperative, however, to properly understand the role of basal extrastriate areas in language processing, as such an understanding may permit us to discover how the brain actually processes language. RP is obtained by means of a considerably low-cost technique, especially considering that it can be recorded simply by using a pair of electrodes and a single channel device. This ease of measurement clearly represents an outstanding advantage for studying these brain regions in comparison with other techniques, such as magnetoencephalography (MEG), positron emission tomography (PET), or functional magnetic resonance imaging (fMRI). Furthermore, and contrasting with PET and fMRI, RP would convey the additional advantage of its excellent temporal resolution. If, on the other hand, the neural generators of RP were not in extrastriate areas, it would be of great interest to know which areas are generating an ERP component that is sensitive to semantic or conceptual phenomena and with the latency of RP.

In this experiment our goal was to identify the topography and neural generators of RP. For these purposes, the stimulation procedures followed in our previous study are replicated here to ob-

tain a good RP (Martín-Loeches et al., 1999). Accordingly, words were presented that could be either semantically correct targets (SCt; names of animals; the subjects had to press a button only if they appeared), semantically correct nontargets (SCn-t; nonanimal nouns), orthographically correct nonwords (OC; nonwords following phonological and orthographical rules), random letters (RL; words formed of unpronounceable sequences of random letters), or control (CN; fragments of words with clearly recognizable non-letters). The standard occipital (Inion-Pz) derivation was used, in addition to a large array of electrodes (60 cephalic leads). In studying RP topography, several referential methods are compared to determine the best one yielding a recognizable RP-like component. This RP-like component must display not only both peak latency and a shape resembling those of the RP obtained with the standard occipital derivation, but also differential amplitude values for the different levels of lexical processing. Thereafter, a brain electrical source analysis (BESA; Scherg, 1990) was applied to determine the possible neural generators of this component.

Methods

Subjects

Twenty-one subjects (13 women; 19–38 years of age, $M = 22.2$ years) participated in the experiment after giving informed consent. All had normal or corrected-to-normal vision. All of the subjects were right handed, with average handedness scores (Oldfield, 1971) of $+0.87$ (range, $+0.41$ to $+1.00$). Spanish was the first language of all subjects.

Stimuli

There were pools of semantically correct (SC), OC, RL, CN, and background (BK) stimuli. The SC stimuli were further divided into two pools of 20 names of animals and 20 nouns that were not animal names. As animal names were used as targets, they were termed SCt (for SC targets), and the nonanimal names as SCn-t (for SC nontargets). The two pools of SC stimuli were of comparable familiarity, according to the Alameda and Cueto (1995) dictionary of frequencies for Spanish. To harmonize them with SC stimuli, the OC, RL, and CN stimuli also comprised 20 elements each, whereas the BK pool comprised 40 stimuli.

Both the SCt and the SCn-t stimuli were two-syllable Spanish words that contained 5 (80% within each pool), 4 (10%), or 6 (10%) letters. The OC stimuli consisted of nonwords that followed phonological and orthographic rules for Spanish but were devoid of meaning and did not approximate to or sound like any meaningful word. They were also two syllables, the number of letters following the same percentages as for the SC stimuli. These OC words were selected on the basis of a previous study with a Spanish population (García-Albea, Sánchez-Casas, & del Viso, 1982). The RL stimuli were nonwords created by randomizing the letters of SCt words and constituting strings of 4, 5, and 6 letters, again in the same percentages as for the SC stimuli. Special care was taken to obtain strings that did not follow Spanish orthographic rules. The CN stimuli were made by cutting SCt words into “n” portions ($n =$ number of letters that compose a word minus one). The portions were replaced always following the same rules: the first piece of the word was placed in the last position of the new stimulus, and vice versa; the penultimate portion was placed in second position, and vice versa; and so on. Every stimulus obtained this way had at least two complete letters, but also clearly identifiable nonletters (formed by the joining of different fragments of letters). Finally, the pool of BK stimuli was composed of

the same 20 CN stimuli together with a new set of 20 stimuli obtained in the same way as the CN stimuli, except that portions were replaced randomly. Special care was taken for the stimuli to have the same main features as the CN letters: every stimulus had at least two complete letters, but also clearly identifiable nonletters. Examples of each type of stimulus are displayed in Figure 1.

All the stimuli were 1.3 cm high and 3.5 cm wide, and all were sprinkled within a 3×6 -cm rectangle of white random dots (5% degradation). This degradation causes some delay in the RP peak (Rudell & Hua, 1997) but the subject can still discern visual aspects and overall physical attributes of the stimuli. The eyes of the subjects were 65 cm from the screen. At that distance images were 1.14° high and 3° wide in their visual angles. All stimuli were presented white-on-black on an NEC computer MultiSync monitor, controlled by the Gentask module of the STIM package (NeuroScan Inc.).

Procedure

Rapid stream stimulation (Rudell, 1992) was used. Accordingly, stimuli were displayed with a stimulus onset asynchrony of 257 ms. The computer displayed mostly BK stimuli. Periodically (after either six or seven BK stimuli, this number being randomized), a test stimulus instead of BK stimuli was presented. The test stimulus could be SCt, SCn-t, OC, RL, or CN. Stimulation was organized in sequences. Each sequence started with six or seven BK stimuli, determined by a random process, followed by the first test stimulus. A random process determined the type of stimulus applied. No more than two of the same type occurred in succession. Six BK stimuli followed the last test stimulus of a sequence. With this procedure, which is standard when using rapid stream stimulation to obtain RP, the possibility exists that expectancy phenomena may develop over the six or seven BK stimuli. However, these phenomena should be identical across type of stimulus (SCt, SCn-t, OC, RL, or CN), because subjects never knew which stimulus was going to appear.

A total of 16 sequences were presented to each subject. Subjects were instructed to press a button every time they detected a word whose meaning was an animal. The subjects were explicitly

told to respond as rapidly as possible, and informed of a payment schedule based on their responses. A response between 650 and 900 ms after target stimuli onset was considered as a hit that earned 5 units, whereas a response between 300 and 650 ms was considered a fast response that earned 10 units. A 25-unit penalty was imposed for responding to stimuli other than targets or for a premature response, one that occurred less than 300 ms after word presentation. At the end of the experimental session, these units were proportionally exchangeable for money.

Each subject was presented with all of the stimuli from the pools. Each sequence contained 5 SCt, 5 SCn-t, 5 OC, 5 RL, and 5 CN stimuli, together with the proportional amount of BK stimuli. The particular instance of a test stimulus was determined randomly. Accordingly, each test stimulus appeared four times to each subject during the session, and could never be repeated within the same sequence.

At the beginning of each sequence, subjects had to push the button so that a message appeared on the screen informing them that they should blink as much as they wanted and push again to start the sequence. When a sequence was over, subjects were provided with feedback of their successes and errors and the number of units they had earned.

Electrophysiological Recordings

Electroencephalographic (EEG) data were recorded using an electrode cap (ElectroCap International) with tin electrodes. A total of 58 scalp locations were used: Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, PO1, POz, PO2, PO4, PO8, O1, Oz, and O2. These labels correspond to the revised 10-20 International System (American Electroencephalographic Society, 1991), plus two additional electrodes, PO1 and PO2 located halfway between POz and PO3 and between POz and PO4, respectively. All scalp electrodes, as well as one electrode at the left mastoid (M1), were originally referenced to one electrode at the right mastoid (M2). The electrooculogram (EOG) was obtained from below versus above the left eye (vertical EOG) and the left versus right lateral orbital rim (horizontal EOG). Electrode impedances were always kept below 3 k Ω . A bipolar recording using the standard procedure for obtaining RP was also performed. Accordingly, one electrode was placed on the Inion and the other on Pz.

A bandpass of 0.3–100 Hz (3 dB points for -6 dB/octave roll-off) was used for the recording amplifiers. The channels were continuously digitized at a sampling rate of 250 Hz for the duration of each task sequence. The buffers were stored in a file along with other relevant information, such as number of trials of each type.

Data Analysis

The continuous recording was divided into 1,024-ms epochs beginning from the onset of each SCt, SCn-t, OC, RL, and CN stimulus. Artifacts were automatically rejected by eliminating those epochs that exceeded $\pm 65 \mu\text{V}$ at any electrode. A visual inspection was also carried out, eliminating epochs with eye movements or blinks. Only correct trials were included in the analyses, also excluding those in which the reaction time was not between 300 and 900 ms. ERP averages were categorized according to each type of stimulus.

Latency and amplitude of RP was measured from average waveforms recorded from the occipital electrodes of the standard procedure (Inion-PZ). Following criteria outlined elsewhere (Rudell

GALLO	SEMANTICALLY CORRECT (TARGET)
SECTA	SEMANTICALLY CORRECT (NON-TARGET)
DEMBU	ORTHOGRAPHICALLY CORRECT
AGSRA	RANDOM LETTERS
_O_AIG	CONTROL
FDCKRE	BACKGROUND

Figure 1. Examples of the images for each type of stimulus. All the stimuli had a rectangle of superimposed random dots (5% degradation).

& Hua, 1997), latency was measured at the most positive peak included in the interval 160–417 ms after test image onset.

For the entire sample of cephalic electrodes, originally M2-referenced data were algebraically re-referenced offline using several methods. These referential methods were: (1) the average of the mastoids (M1 + M2); (2) a nearest-neighbor, planar Laplacian derivation from the five nearest surrounding electrodes (Hjorth, 1975, 1980); and (3) a global average reference (Lehmann, 1987). Results obtained with each reference method, including originally M2-referenced results, were tested to find the best method yielding a recognizable RP-like component in other than the standard bipolar occipital derivation. Again, both latency and amplitude of this RP-like component were measured, as was its topography.

The BESA algorithm (Scherg, 1990) was also used with the entire sample of cephalic electrodes. This method compares the distribution of voltage that would be produced by a proposed set of dipoles with the observed distribution. Positions and orientations of the dipoles can be adjusted iteratively to obtain a better fit between the observed and computed voltage distributions. As a result, the percentage of variance explained by the proposed dipoles within a time range is obtained, and this value is considered to be acceptable if it is higher than 90% (Scherg, 1992). Using BESA, it is recommended to use constraints based on known anatomy and physiology of the system being analyzed (Scherg & Berg, 1991). Therefore, we tested several sets of dipoles based on previous anatomical studies with PET, fMRI, MEG, or intracerebral recording of language semantic processing to determine which method, if any, provided an adequate model of RP. As an alternative, we also used the approach of situating vertically oriented dipoles at the center of the sphere (neutral position and orientation) and allowing the program to fit automatically both position and orientation. When the results obtained with this alternative method coincide with those obtained with the anatomical and physiological constraints, dipole solution becomes enhanced.

Results

Performance

Of the 8,400 trials (each of five types of stimulus, repeated five times for each one of 16 sequences in 21 subjects), 1.7% were excluded because eye blinks were detected. An additional 0.16% of trials were excluded due to premature or late responses. Trials with omissions and false alarms were also excluded, which represented 2.23% and 1.18%, respectively. Mean reaction time was 533 ms.

Electrophysiology

For two subjects, occipital derivation (Inion-Pz) data were unavailable, as the data were lost due to a faulty amplifier channel. Figure 2 displays the grand-mean average waves in the Inion-Pz derivation. The responses for CN trials were subtracted from each of the waveforms to eliminate driving and enhance language-related factors. Both SC stimuli presented an RP with the highest amplitude, that of SCt being larger than that of SCn-t (4.3 and 3.6 μV , respectively). The two SC stimuli also presented the same peak latencies (276 ms each). Figure 2 also shows that OC and RL stimuli again displayed some degree of RP, the RP for RL stimuli (2.1 μV) appearing smaller than that for OC stimuli (2.5 μV), which in turn was smaller than the RP for either of the SC stimuli. Also, the latency of the RP for OC stimuli was 284 ms, whereas it was 272 ms for RL stimuli.

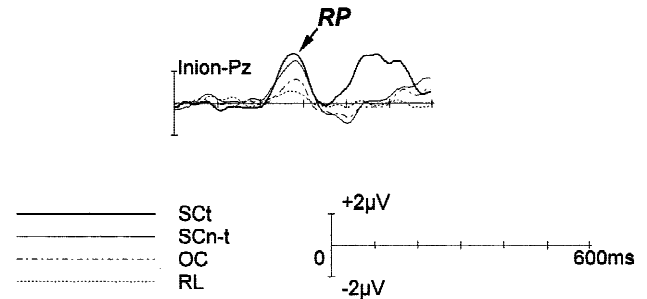


Figure 2. Absolute grand-average waveforms after subtracting control trials from each of the waveforms for each type of stimulus. Data correspond to the occipital standard (Inion-Pz) derivation. The mean recognition potential (RP) latency for this derivation was about 277 ms. A clear RP can be identified for both semantically correct target (SCt) and nontarget stimuli (SCn-t). Random letters (RL) and orthographically correct (OC) stimuli also displayed an RP. Interestingly, however, the RP amplitude gradually increased as the level of lexical access required for each type of stimulus increased.

An analysis of variance (ANOVA) comparing RP latencies at this Inion-Pz derivation yielded nonsignificant results, $F(3,54) = 1.03$, $p > .1$, $\epsilon = 0.730$. Therefore, the same peak latency could be assumed across types of stimulus. To measure amplitude for statistical analyses, a narrow window was established centered on the overall mean peak amplitude (about 277 ms), and ranging from 248 to 304 ms (around mean ± 30 ms) after stimulus onset. Amplitude measures were subjected to a repeated-measures ANOVA, with type of stimulus as factor that could exhibit one of five values (SCt, SCn-t, OC, RL, or CN). ANOVA results revealed that the factor, type of stimulus, was significant, $F(4,54) = 26.9$, $p < .0001$, $\epsilon = 0.933$, indicating that RP amplitude differed as a function of type of stimulus in this occipital derivation. Post hoc analyses with the Bonferroni correction revealed that the RP for SCt and SCn-t did not differ significantly in amplitude, $F(1,18) = 8.1$, $p > .1$, whereas both presented significantly higher amplitudes when compared with nonwords, both when compared with OC stimuli, $F(1,18) = 35.2$ when comparing SCt with OC and $F(1,18) = 26.7$ when comparing SCn-t with OC ($p < .001$ in either case), and with RL stimuli, $F(1,18) = 64.6$ when comparing SCt with RL and $F(1,18) = 19.1$ when comparing SCn-t with RL ($p < .001$ in either case). The same was true when comparing SC with controls, $F(1,18) = 75.5$ when comparing SCt with CN and $F(1,18) = 77.1$ when comparing SCn-t with CN ($p < .0001$ in either case). Finally, the comparison between OC and RL stimuli showed that they did not differ significantly, $F(1,18) = 2.6$, $p > .1$. With the exception of the absence of a significant difference between OC and RL, these results largely resemble those obtained in our previous study (Martín-Loeches et al., 1999).

To elucidate the topography of RP, attention was focused on the amplitude, shape, and latency of the components around 277 ms in the total array of electrodes after applying each referential method. Again, CN stimuli were subtracted from each of the waveforms. As stated earlier, the best candidate for an RP-like component must display not only both peak latency and a shape resembling those of the RP obtained with the standard occipital derivation, but also differential amplitude values to the different levels of lexical processing. Our findings: first, the original raw data (M2-referenced) had a negative component peaking maximally at PO7 for all types of stimulus; its latency varied from 298 to 320 ms across types of stimulus, and the amplitudes at PO7 were around $-2.9 \mu\text{V}$ for

SCT, $-2.4 \mu\text{V}$ for SCn-t, $-1.4 \mu\text{V}$ for OC, and $-0.8 \mu\text{V}$ for RL stimuli. Next, the average of the mastoids yielded a positive component peaking maximally at Fpz, Fz, and Fp1, with a latency ranging between 264 and 300 ms and amplitudes of around $3 \mu\text{V}$ for both SC stimuli (measured at Fp1 for SCT and at Fz for SCn-t), $1.82 \mu\text{V}$ for OC (Fpz), and $1.1 \mu\text{V}$ for RL (Fpz). The Laplacian derivation yielded a negative component peaking maximally at PO7 for all types of stimulus except RL, which showed a PO8 maximum; its latency varied from 268 to 276 ms and the amplitudes at PO7 were $-1.4 \mu\text{V}$ for SCT, $-1.2 \mu\text{V}$ for SCn-t, and $-0.6 \mu\text{V}$ for OC; at PO8 the amplitude was $-0.5 \mu\text{V}$ for RL stimuli. Last, average reference yielded a negative component peaking maximally at PO7 for all types of stimulus except RL, which also showed a PO8 maximum; its peak latency was around 268–284 ms, and the amplitudes were $-4.5 \mu\text{V}$ for SCT, $-3.8 \mu\text{V}$ for SCn-t, and $-2.4 \mu\text{V}$ for OC; at PO8 the amplitude was $-1.9 \mu\text{V}$ for RL stimuli. A frontal positivity could also be observed, partially coinciding in time with the parieto-occipital negativity.

After cautiously examining all these results, it was concluded that the best way to obtain a good and remarkable RP-like component was the average reference method. Original (M2-referenced) data offered a good option, but all potential processes near the right mastoid would be smeared to some degree. Average mastoids presented the same problem, but were enhanced by including the left

mastoid. In addition, this procedure yielded a frontal maximum, which appears to be far from related to a component obtained in occipital derivations. The nearest-neighbor procedure yielded plausible and valuable results. However, peripheral sites cannot be calculated accurately with this method (Hjorth, 1975, 1980), so it has been recommended that peripheral sites not be taken into consideration. As the maxima with this method were obtained at peripheral electrodes (PO7, PO8), these data should (theoretically) not be taken into consideration. By contrast, the best procedure appeared to be the average reference method. This method was free of the problems reported for the other methods, presenting by contrast an RP-like component with highly similar latencies and shape to that observed in the standard derivation. Its maximum was located at sites (PO7, PO8) in consonance with other referential methods (raw M2-referenced, Laplacian derivation). Also, and now in agreement with the data obtained with the linked mastoids reference, a frontal positivity partially coinciding in time with the parieto-occipital negativity could be observed. Finally, the average reference method showed the largest amplitude values for this RP-like component. Accordingly, the remaining data description, including both maps and statistical analyses, shall refer to the data obtained with the average reference method. Figure 3 displays the grand-mean average waves in the PO7 and PO8 electrodes for the average referenced data. The responses for CN trials were again

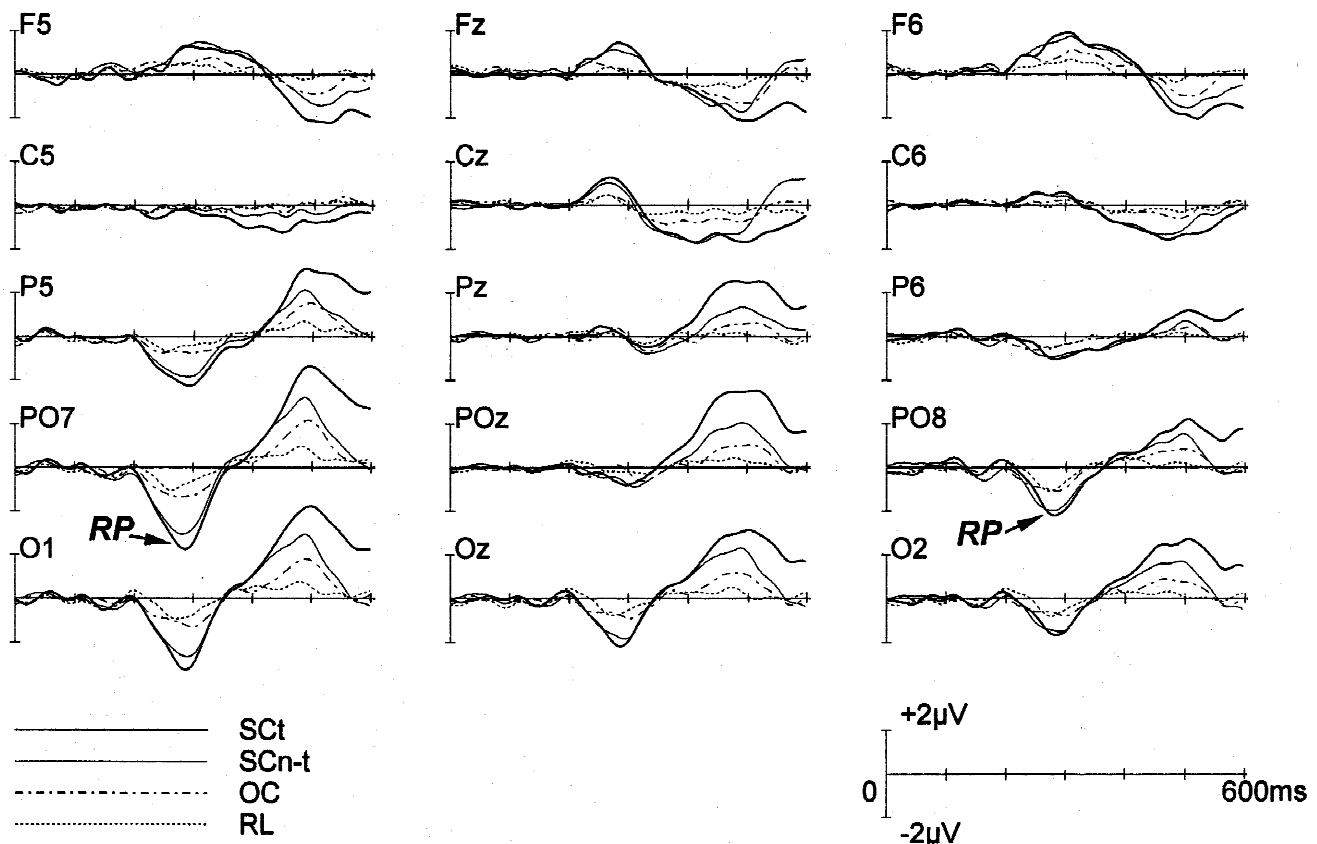


Figure 3. Absolute grand-average waveforms after subtracting control trials from each of the waveforms for each type of stimulus, but now corresponding to the average-referenced results in a selection of electrodes. The mean recognition potential (RP) latency for these data was about 276 ms. The RP can again be identified for the random letters (RL), orthographically correct (OC), and both types of semantically correct stimuli (target and nontarget, SCT and SCn-t, respectively). Again, the RP amplitude gradually increased as the level of lexical access required increased, but this increase was evident mainly at PO7. Furthermore, and interestingly, the SCT stimuli displayed significantly larger RP amplitudes than the SCn-t at this electrode.

subtracted from each of the waveforms. Contrasting with the component in Figure 2 (standard derivation), the RP appears now with negative polarity. This finding is due to the fact that the RP is obtained in the standard (occipital) derivation by connecting the Inion to the negative grid of the differential amplifier, whereas the opposite is true (following conventional procedures) for the total array of the 60 cephalic electrodes.

An ANOVA was conducted to determine whether the latency of the RP-like component observed at PO7 and PO8 differed across types of stimulus. This ANOVA yielded nonsignificant results, $F(3,60) = 0.4$ and $F(3,60) = 1.7$ for PO7 and PO8, respectively, $p > .1$ in both cases, $\epsilon = 0.448$ and $\epsilon = 0.804$, respectively. Moreover, in both electrodes the overall mean latency was exactly the same: 276 ms. Accordingly, a single time window was used to measure amplitude for maps and statistical analyses. This window was centered on the overall mean peak amplitude, and comprised the period from 248 to 304 ms (around mean ± 30 ms) after stimulus onset.

The maps of the average referenced activity in the 248–304-ms period for each of the stimulus types are displayed in Figure 4.

Again, activity in response to CN stimuli was subtracted from each of the waveforms to make the maps. Two findings are clear: First, the topography of the maps is similar, and could be described roughly as a bilateral inferior parieto-occipital (PO7, PO8) negativity, with a positive counterpart of lower intensity over frontal and frontopolar regions. Nevertheless, there is also a subtle difference between types of stimulus, as there was a gradual trend from a left-sided lateralization of RP for SCt stimuli to a bilateral distribution for RL. Second, the RP-like amplitude at PO7 and PO8 decreased progressively from SCt to RL stimuli, which was especially evident for PO7.

With the aim of avoiding an unacceptable degree of loss of statistical power due to the use of a high number of electrodes (Oken & Chiappa, 1986), statistical analyses were planned and made on a selected sample of 30 of the total of 60 electrodes. These 30 selected electrodes were: Fp1, Fp2, AF3, AF4, F5, F1, F2, F6, FC5, FC1, FC2, FC6, C5, C1, C2, C6, CP5, CP1, CP2, CP6, P5, P1, P2, P6, PO7, PO1, PO2, PO8, O1, and O2. A four-way ANOVA was performed on the mean amplitude in the 248–304-ms window with three repeated-measures factors: type of

RECOGNITION POTENTIAL

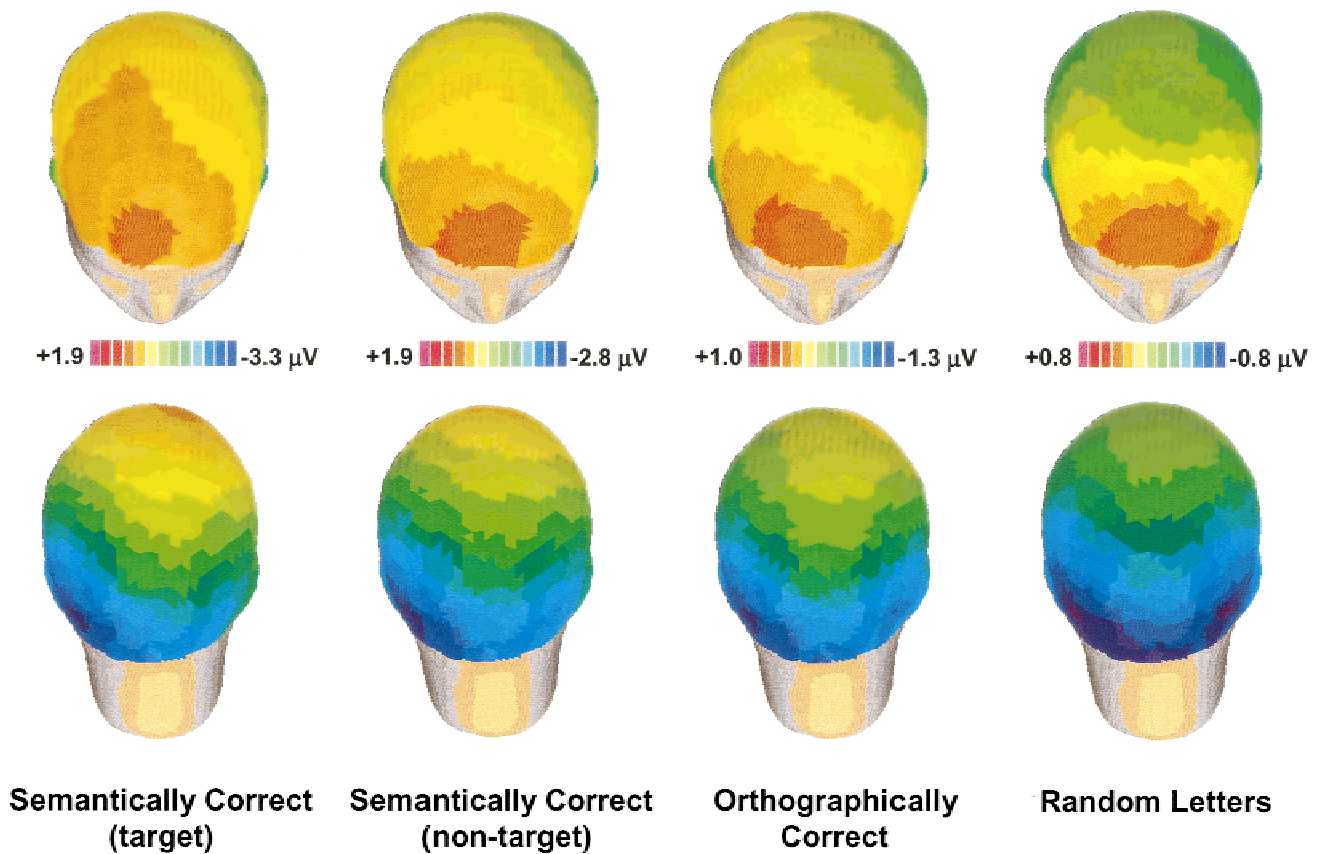


Figure 4. Topographic maps of the recognition potential (RP) distribution across the total array of 60 cephalic electrodes after recalculating original data to an average reference. They represent mean values for the period 248–304 ms. Again, activity to control stimuli has been subtracted from each of the waveforms to make the maps. Note that individual color scales for amplitude values have been used. The topography of all the maps appears markedly similar, consisting of a bilateral inferior parieto-occipital negativity together with a lower amplitude positivity over frontal and frontopolar regions. The RP amplitude decreased progressively from semantically correct target to random letters stimuli, a change that was particularly evident for the left side.

stimulus as a factor that could exhibit one of five levels (SCt, SCn-t, OC, RL, or CN); electrode (15 levels); and hemisphere (2 levels). Sex (female, male) was considered as a between-subject factor because sex dimorphism has been reported previously with regard to language areas (e.g., Harasty, Double, Halliday, Kril, & McRitchie, 1997).

Results showed significant effects of type of stimulus, $F(4, 76) = 10, p < .0001, \epsilon = 0.708$; electrode, $F(14, 266) = 67.8, p < .0001, \epsilon = 0.119$; hemisphere, $F(1, 19) = 6.7, p < .01, \epsilon = 1.000$; and the interactions Type of stimulus \times Electrode, $F(56, 1064) = 30.7, p < .0001, \epsilon = 0.008$; Type of stimulus \times Hemisphere, $F(4, 76) = 11.8, p < .0001, \epsilon = 0.587$; and Type of stimulus \times Electrode \times Hemisphere, $F(56, 1064) = 4.4, p < .0001, \epsilon = 0.113$. The variable sex did not yield any significant result, either alone or interacting with any other factor.

Post hoc analyses were performed, but we used only those electrodes that showed the larger RP-like values across types of stimulus, that is, PO7 and its contralateral PO8. In this regard, an ANOVA with type of stimulus as factor was carried out, followed by post hoc comparisons with the Bonferroni correction at each of the two electrodes separately. Results at PO7 showed that each type of stimulus was significantly different when compared with one other, $F(1, 20) = 11.76\text{--}119.6, p < .0001$ in all cases except the comparison SCt versus SCn-t, with $p < .05$. At PO8, however, SCt and SCn-t did not differ, $F(1, 20) = 0.008, p > .1$, whereas the two SC types of stimuli differed significantly when compared with all the other types, $F(1, 20) = 14.3\text{--}38.8, p < .01$ in all cases. Also, the comparison between OC and RL stimuli at PO8 did not yield a significant result, $F(1, 20) = 1.1, p > .1$, whereas CN stimuli always presented significantly less amplitude than either OC or RL stimuli, $F(1, 20) = 18.7$, and $F(1, 20) = 16.5$, respectively, $p < .01$ in both cases. Thus, statistical analyses supported the existence of amplitude differences across types of stimuli, both at PO7 and PO8, but more markedly so in the case of PO7.

As already mentioned, the maps in Figure 4 also seem to display some degree of laterality, but only for certain types of stimuli. This finding is supported by the Type of stimulus \times Hemisphere and the Type of stimulus \times Electrode \times Hemisphere significant interactions. To further elucidate this finding, a post hoc analysis was again performed, but on this occasion pairwise PO7 versus PO8 comparisons were made for each type of stimulus. Again, the Bonferroni correction was applied. Remarkably, no PO7–PO8 comparison yielded significance, $F(1, 20) > 0.004\text{--}7.3, p > .1$ in all cases. Hence, and to enhance the apparent lateralities, the activity to CN stimuli was subtracted from each of the other types of stimuli (the same procedure followed in making the maps and obtaining the curves). This method yielded different results. Now, PO7 presented significantly larger RP-like amplitude in both SCt and SCn-t stimuli, $F(1, 20) = 15.8$ for SCt stimuli, $F(1, 20) = 9.6$ for SCn-t stimuli, $p < .01$ in both cases. Thus, statistical analyses supported to some extent the existence of amplitude differences between hemispheres for SC stimuli, but not for OC and RL stimuli. This finding is in agreement with the maps in Figure 4.

The next step in the data analysis was the application of the BESA algorithm to determine the neural sources of the RP-like potential. However, a previous calculation appeared essential, to confirm whether or not the topography differed across types of stimuli. If the same topography could be assumed, independently of subtle differences in laterality, the same generators for all types of stimuli could be firmly supposed (Rugg & Coles, 1995). Hence, a profile analysis (McCarthy & Wood, 1985) was performed. For the time window of interest (248–304 ms) in the difference waves

(that is, after subtracting CN stimuli from each of the other types of stimulus), mean amplitudes were scaled for each subject across all electrodes, with average distance from the mean, calculated from the grand mean ERPs, as denominator. Significant differences in ANOVAs with these scaled data, in which possible effects of source strength are eliminated, provide unambiguous evidence for different scalp distributions.

An ANOVA was therefore performed on these scaled data with type of stimulus (four levels: SCt, SCn-t, OC, RL) and electrode (30, as on this occasion they were not dissociated by hemisphere) as factors. However, this ANOVA yielded no significant results in the Type of stimulus \times Electrode interaction, $F(87, 1740) = 1.4, p > .1, \epsilon = 0.217$. Further, in an attempt to increase the power of profile analyses, post hoc ANOVAs with the transformed data were performed, comparing each type of stimulus with one another separately. Again, no significant differences were observed in any comparison, $F(29, 580) = 0.4\text{--}2.4, p > .1$ in all cases. Accordingly, the assumption of the same generators across types of stimulus appeared to be well supported, with subtle amplitude differences probably being due to differences in intensity of activity of these generators across types of stimulus.

At this stage, therefore, the BESA algorithm was applied assuming that all four types of stimuli of interest (SCt, SCn-t, OC, and RL) presented the same topography and, hence, the same generators. From Figure 4 the most plausible situation appeared to be the existence of two generators at contralateral homologue areas. This assumption was supported by the existence within each hemisphere of maxima at PO7 and PO8, together with a polarity-inverted lower intensity activity over prefrontal regions. Additionally, this was confirmed by current source density (CSD) maps (Pernier, Perrin, & Bertrand, 1988). This technique helps determine the number of sources, as strong discrete foci in CSD maps indicate a source that is most likely near the region of maximal density. CSD maps were performed on our data (not shown) in the time window of interest, and clearly indicated the existence of two sources, one near PO7 and the other near PO8. This finding was obvious even for the SCt stimuli data, the most lateralized map. These maps, nevertheless, located the counterpart activity over midline parietal regions.

Given the better amplitude values, the best signal-to-noise ratio could be expected in the data for SCt stimuli. Therefore, dipole modeling was based on these data. Testing of dipole solutions for the other types of stimuli appeared unnecessary, given the previously established assumption of the same generators across types of stimuli. Using constraints based on known anatomy and physiology of the system being analyzed, a total of 11 anatomical positions were tested. They were selected according to a review of recent studies on the neurophysiological basis of semantic processing with PET, fMRI, MEG, or intracerebral recording or stimulation. The anatomical positions probed were: middle temporal gyrus (Binder et al., 1997; Chee, O'Craven, Bergida, Rosen, & Savoy, 1999; Démonet et al., 1992; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996); inferior temporal gyrus (Binder et al., 1997; Démonet et al., 1992; Vandenberghe et al., 1996); parietotemporal area (Démonet et al., 1992; Kuriki et al., 1998; Vandenberghe et al., 1996); superior occipital gyrus (Vandenberghe et al., 1996); fusiform gyrus (Binder et al., 1997; Bookheimer, Zeffiro, Blaxton, Gaillard, & Theodore, 1995; Chee et al., 1999; Kuriki et al., 1998; Lüders et al., 1991; McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre et al., 1994; Nobre, Allison, & McCarthy, 1998; Vandenberghe et al., 1996); lingual gyrus (Kuriki et al., 1998; Petersen, Fox, Posner, Mintum, & Raichle, 1988; Petersen, Fox, Snyder, &

Raichle, 1990); Wernicke's area (composed of posterior third of BA22 and immediately adjacent parts of BA39-40) (e.g., Binder et al., 1997); angular gyrus (Binder et al., 1997; Menard, Kosslyn, Thompson, Alpert, & Rauch, 1996); hippocampus (Vandenberghe et al., 1996); and parahippocampal gyrus (Binder et al., 1997). Although posterior sources appeared the most plausible, frontal dipoles were also tested, given both the counterpart frontal activity in the maps of Figure 4 and the persistent finding of a frontal area, around left inferior frontal gyrus or BA47, involved in semantic processing (Binder et al., 1997; Chee et al., 1999; Petersen et al., 1990).

Each region was tested separately. The two dipoles followed the constraint of being at mirror positions and presenting mirror orientations. Dipoles were placed in the approximate areas that corresponded to each anatomical position, moving the position gradually within each region and simultaneously adjusting dipole orientation. The only solutions that explained more than 90% of the variance were within the following regions: lingual gyrus (96.64%), fusiform gyrus (95.61%), hippocampus (94.78%), and parahippocampal gyrus (93.88%). Automatic fitting procedure was also applied. The solution with this method clearly coincided with the position within the lingual gyrus. Thus, it appears evident that the best position for the neural generators of the RP-like component is within the lingual gyrus. The three-dimensional coordinates for this generator of the RP-like component within the lingual gyrus were: 61.12% eccentricity; -113 theta location; 64.86 location angle phi (-20.32 , -43.31 , and -20.26 for x , y , and z coordinates at Cartesian locations). These coordinates correspond to dipole 1, dipole 2 being at the same location but at contralateral mirror positions. Figure 5

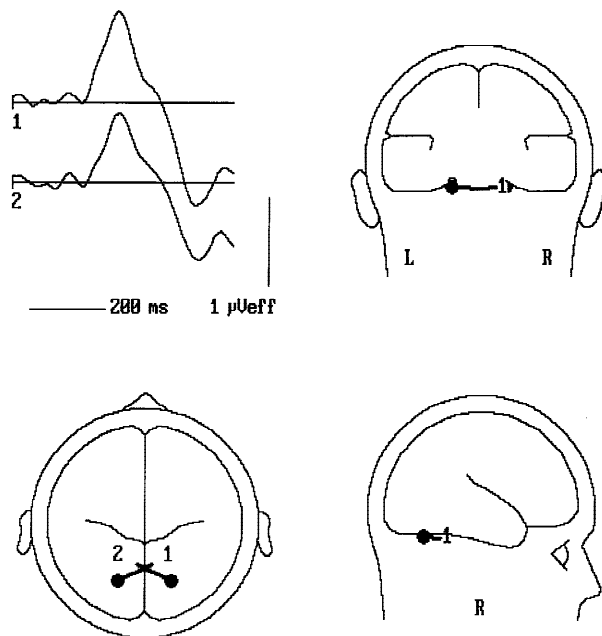


Figure 5. Time-varying source magnitude waveforms (top left) and positions (top right and bottom) of the two dipoles for the recognition potential. Numbers identifying each dipole are located near the sharp end of the vector representing their orientation. That is, dipole number 1 is located within the left hemisphere, whereas number 2 is within the right hemisphere. They made up the best-fit solution found for the 248–304-ms time range, and their location corresponds to the lingual gyri. They are based on the waves for semantically correct target stimuli after subtracting the activity to control stimuli.

shows the position, orientation, and source waveforms (magnitude over time) of this best-fitting dipole solution.

Finally, a different and additional finding can be observed in Figure 3, although not directly related to RP. After the RP a subsequent positivity in parieto-occipital electrodes is evident that decreased in amplitude gradually when moving from SCt to RL stimuli; this portion of the wave therefore resembled the RP but with inverse polarity. It peaked at about 488 ms after stimulus onset (ranging from 480 to 492 ms). A map (not shown) was made for every type of stimulus in the corresponding time interval (460–516 ms); the topography appeared identical to that for RP-like activity (248–304 ms) but with polarity inverted.

Discussion

Our findings demonstrated that RP is an electrophysiological response of the brain sensitive to semantic or conceptual factors and originating within the basal extrastriate areas (fusiform and lingual gyri). Both the lingual and the fusiform gyri appear to be strongly involved in semantic processing, although their specific and differential roles in these processes are still unclear (Büchel et al., 1998; Hagoort et al., 1999).

The specific neural generator of the RP appears to be within the lingual gyrus, although its origin within the fusiform gyrus or other immediately adjacent structures, such as the parahippocampal gyrus, cannot be ruled out. In fact, the BESA algorithm applied here implies the trade-off of using a spherical head model, that is, a nonrealistic model with a certain degree of associated anatomical inaccuracies (Scherg, 1992). Accordingly, we shall mention the basal extrastriate areas here as mainly referring to lingual/fusiform gyri as a whole, without further subdividing these relatively extensive areas. Certainly this precision is more or less the highest that one should accept using ERP-BESA analyses. Nevertheless, in this way we are imitating authors who used other techniques with better spatial resolution than EEG (e.g., Kuriki et al., 1998).

Our finding that RP was significantly larger in the left hemisphere when the stimuli belonged to the SCt (animals), as compared with other semantically correct but nontarget stimuli, indicates directly that RP is sensitive not only to the presence of semantic content in the stimuli but also to the presence of a specific semantic content. This result could not be attributed to a target effect due to the target status of the SCt stimuli, as the difference between semantically correct targets and nontargets was the same as the difference between semantically correct nontarget and other nontarget stimuli. This sensitivity to the specific semantic content of the stimuli was a surprising but remarkably important new result of the present study. Given that the time at which the RP appears is also clearly coincident with that expected for semantic analysis (Serenio et al., 1998), and that the RP is also elicited by pictures (Rudell, 1992), it can be stated that the RP is a robust candidate to be the preferred ERP component for studying semantic processing along its occurrence. The fact that RP to pictures (Rudell, 1992) is exactly the same as the RP to words, because they were equated in topography and neural generators, has been confirmed recently in a study applying the technical procedures presented here (Hinojosa, Martín-Loeches, Gómez-Jarabo, & Rubia, 2000).

The fact that SCn-t, OC, and RL stimuli all displayed an RP and presented the same topography as the SCt stimuli is not an obstacle to considering RP as a useful component for studying semantic or conceptual processing with ERP. To explain why an RP appeared as a result of stimuli devoid of semantic content, and to explain the amplitude difference between SCt and SCn-t stimuli, we might

consider attentional processes. Hence, and as in traditional selective attention studies (e.g., Mangun & Hillyard, 1995), the area generating the RP observed here would increase its amplitude to the extent that the stimulus resembles the attended one. In this case, nevertheless, a primary perceptual property would not be attended, but rather a conceptual category. In line with this, Nobre et al. (1998) reported intracerebral recordings showing comparable attention effects to words due to top-down influences from downstream regions within the fusiform gyrus involved in word processing. Nobre et al. (1998) determined that attentional top-down processes constituted the “most parsimonious” explanation. Whatever the case, the reaction of basal extrastriate areas to OC and RL stimuli fits well with the previously mentioned reactivity of these areas to several levels of lexical processing, though highest activation is displayed for semantic-content stimuli (Price, 1997).

Indeed, the RP amplitude differences between types of stimuli cannot be attributed to other factors, such as P300-related phenomena in which the detection of a stimulus as target determines its full amplitude. Rudell (1991), Rudell, Cracco, Hassan, and Eberle (1993), and Rudell and Hua (1997) have already demonstrated that RP is absolutely unrelated to P300, because RP is completely insensitive to many crucial variables that affect P300, such as stimulus probability. Also, another nonsemantic variable such as familiarity of the stimuli, which could not be entirely ruled out for explaining amplitude differences between types of stimuli in our previous study using only the Inion-Pz derivation (Martín-Loeches et al., 1999), can now be discarded. Actually, SCt and SCn-t were equally familiar, but SCt showed the highest RP amplitude over the left hemisphere.

By considering all of these findings and the literature relating to both RP and the basal extrastriate areas, it now appears feasible to make a more complete description of the possible role of these areas in language processing. These areas appear to be sensitive to words more than to pseudowords, and this sensitivity is higher in the left hemisphere. This assertion is not only in accordance with the data of our present study, but also with the data from several authors obtained with other techniques, and holds for both the fusiform gyrus and the lingual gyrus (e.g., Bookheimer et al., 1995; Hagoort et al., 1999; Kuriki et al., 1998; Price, 1997; Vandenberghe et al., 1996). Furthermore, it seems that these areas can be activated independent of the input modality (Binder et al., 1997;

Büchel et al., 1998), and also apparently independent of arbitrary language signs, because they can be activated equally by pictures (Hinojosa et al., 2000; Rudell, 1992; Vandenberghe et al., 1996).

These findings to some extent contradict the assertion by Lüders et al. (1991) that basal extrastriate areas represent a mere store for verbal engrams, independent of object recognition. Also, their sensitivity to pictures and their significantly increased activity to stimuli belonging to a given semantic category would contradict the assertion that these areas are a mere intermediate step between the recognition of a specific item and its semantic association (Bookheimer et al., 1995; Kuriki et al., 1998; Petersen et al., 1988).

Additional findings indicate further that the activity within basal extrastriate areas are related to more complex functions than mere object recognition, to the recognition of complex conceptual categories such as tools, animals, or even complex features such as individual human faces (Damasio, 1985; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Sergent, Ohta, & MacDonald, 1992; Thompson-Schill, Aguirre, D’Esposito, & Farah, 1999; Tranel, Damasio, & Damasio, 1997). On the one hand, simple object recognition would be based on the so-called ventral visual system (e.g., Tootell, Dale, Sereno, & Malach, 1996), which interestingly ends in the inferotemporal cortex and some portions of the basal extrastriate areas; on the other hand, different portions of the basal extrastriate areas appear to be modality independent, can be activated by either pictures or words, and subserve the recognition of complex conceptual categories. Accordingly, these portions of the basal extrastriate areas would be good candidates to form part of a system constituting a final step of the perceptual act. These regions appear to be the origin of RP. Interestingly, recent findings indicate that within basal extrastriate areas functions such as conscious awareness without perception are subserved (Ffytche et al., 1998). Returning to the question of considering lingual/fusiform gyri as a whole, the role of the lingual gyrus, the most probable candidate to contain the source of RP, might certainly be different one from that of the fusiform gyrus in conceptual processing. This role, however, despite being unclear, appears to be of a higher degree than that of the fusiform gyrus (Hagoort et al., 1999; Price et al., 1997).

All of the evidence set out and assertions made might be better understood and integrated by means of the tentative proposal of neural organization for language processing displayed in Figure 6.

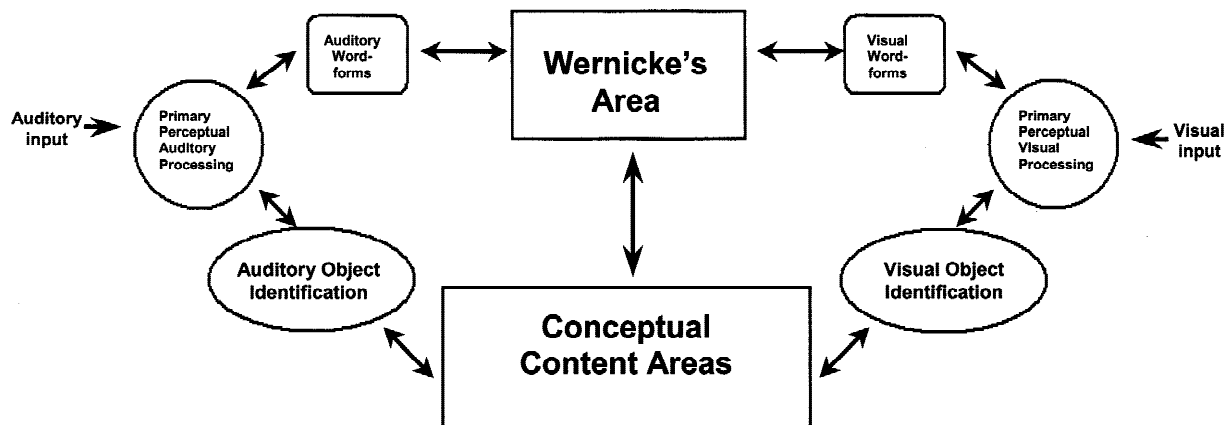


Figure 6. Schematic representation of the processes presumably involved in lexical access and word comprehension. Arrows represent reciprocal connections. This neural organization for language processing is based largely on the findings in the literature on recognition potential and the basal extrastriate areas, which would mainly belong to what is referred to here as “Conceptual Content Areas.”

According to this sketch, auditory and visual primary and secondary areas identify primary perceptual features of language stimuli, information that would independently activate either the auditory or the visual word-form area. On the other hand, other areas (portions of the basal extrastriate included) would be a store for conceptual categories that would be activated by object identification routes. Wernicke's area would be a coordinator between word-form or perceptual areas specialized in analyzing language input information and conceptual content areas such as those within basal extrastriate areas. Evidence for this role of Wernicke's area has been reviewed by Mesulam (1998). This coordinating function ascribed to Wernicke's area can be efficiently achieved thanks to the special disposition of this region relative to basal temporal or extrastriate areas. Certainly, the white matter underlying both basal extrastriate areas and Wernicke's area are in direct contact, which might favor interaction between them (Lüders et al., 1991).

Stimulus repetition effects may be argued as a confound in our design, because each test stimulus, whether SCt, SCn-t, OC, RL, or CN, was repeated four times in each experimental session. This situation is common to all RP research, though in the present study the degree of repetition exhibited one of the lowest values. Although no experiment has been conducted to study directly how repetition effects affect RP response, there are experiments dealing with similar processes, or in which repetition effects could be tested to some extent, and all of them lead to the conclusion that RP appears to be insensitive to repetition effects. For example, neither word priming (Rudell & Hua, 1996b) nor familiarity (Rudell, 1999; Rudell & Hua, 1997) affected RP amplitude or its wave-shape, even when the priming word was the same as the test word. Only latency appears to be affected by these factors, but this measurement was not a major aspect covered by the present study. Also, in a previous study of ours (Martín-Loeches et al., 1999), Experiments 1 and 2 did not differ in RP amplitude, RP wave-shape, or differential amplitude values of RP to the different levels of lexical processing, although the degree of repetition differed greatly and significantly between the two experiments. Further

research appears mandatory, nevertheless, to directly elucidate the possible influence of repetition effects on RP.

Also worthy of mention is the question of why RP was obtained with the present stimulus parameters but not with others. The main ERP component related to semantic processing has been the N400. The N400 is usually obtained by time-locking ERPs to the final words of phrases, the N400 amplitude varying as a consequence of the degree of semantic incongruence of the word relative to the context of the sentence. Accordingly, and given its timing and the stimulation paradigm used to elicit it, the N400 appears more likely to reflect semantic integration, and not the semantic processing of individual words (although, occasionally, an N400 has been reported to individual words, see Nobre et al., 1994). By contrast, semantic processing of individual words is the main task in RP paradigms, in which stimuli are devoid of context and have to be analyzed on a single basis.

Finally, mention should be made of both the absence of sex differences in the topography of RP and its relative left-hemisphere lateralization for SC stimuli. Sexual dimorphism has been suggested in relation to the other area specialized in language processing, Wernicke's area, which might to some extent be larger or even bilateral (as opposed to left-lateralized) in female subjects (e.g., Harasty et al., 1997; Jacobs, Schall, & Cheibel, 1993). However, and according to our data, this dimorphism does not hold for the activity of the basal extrastriate areas, as they are activated with a similar magnitude and left dominance in both female and male individuals. This finding constitutes, furthermore, additional evidence for the overall left-hemisphere specialization of language functions.

In conclusion, it can be asserted that the origin of RP appears to be within the basal extrastriate areas. RP becomes, accordingly, a low-cost tool (that can be obtained with a simple Inion-Pz derivation) of great interest for the study of both language processing and the role of basal extrastriate areas in these processes. Also, research on the potential use of RP in the diagnosis and evaluation of basal extrastriate language disorders appears highly promising.

REFERENCES

- Abdullaev, Y. G., & Posner, M. I. (1998). Event-related brain potential imaging of semantic encoding during processing single words. *Neuroimage*, *7*, 1–13.
- Alameda, J. R., & Cueto, F. (1995). *Diccionario de frecuencias de las unidades lingüísticas del castellano*. Oviedo, Spain: Universidad de Oviedo.
- American Electroencephalographic Society. (1991). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *3*, 38–42.
- Binder, J. R., Frost, J. A., Hammeke, T. A., Cox, R. W., Rao, S. M., & Prieto, T. (1997). Human brain language areas identified by functional magnetic resonance imaging. *Journal of Neuroscience*, *17*, 353–362.
- Bookheimer, S. Y., Zeffiro, T. A., Blaxton, T., Gaillard, W., & Theodore, W. (1995). Regional cerebral blood flow during object naming and word reading. *Human Brain Mapping*, *3*, 93–106.
- Büchel, C., Price, C., & Friston, K. (1998). A multimodal language region in the ventral visual pathway. *Nature*, *394*, 274–276.
- Chee, M. W. L., O'Craven, K. M., Bergida, R., Rosen, B., & Savoy, R. L. (1999). Auditory and visual word processing studied with fMRI. *Human Brain Mapping*, *7*, 15–28.
- Chwilla, D. J., Brown, C. M., & Hagoort, P. (1995). The N400 as a function of the level of processing. *Psychophysiology*, *32*, 274–285.
- Damasio, A. R. (1985). Disorders of complex visual processing: Agnosias, achromatopsia, Balint's syndrome, and related difficulties of orientation and construction. In: M. M. Mesulam (Ed.), *Principles of behavioral neurology* (pp. 259–288). Philadelphia: F.A. Davis.
- Damasio, H., Grabowski, T. J., Tranel, D., Hichwa, R. D., & Damasio, A. R. (1996). A neural basis for lexical retrieval. *Nature*, *380*, 499–505.
- Démonet, J. F., Chollet, F., Ramsay, S., Cardebat, D., Nespoulous, J. -L., Wise, R., Rascol, A., & Frackowiak, R. (1992). The anatomy of phonological and semantic processing in normal subjects. *Brain*, *115*, 1753–1768.
- Ffytche, D. H., Howard, R. J., Brammer, M. J., David, A., Woodruff, P., & Williams, S. (1998). The anatomy of conscious vision: An fMRI study of visual hallucinations. *Nature Neuroscience*, *1*, 738–742.
- Fuster, J. M. (1997). *The prefrontal cortex. Anatomy, physiology, and neuropsychology of the frontal lobe*. Philadelphia: Lippincott-Raven.
- García-Albea, J. E., Sánchez-Casas, R. M., & del Viso, S. (1982). Efectos de la frecuencia de uso en el reconocimiento de palabras. *Investigaciones Psicológicas*, *1*, 24–61.
- Hagoort, P., Indefrey, P., Brown, C., Herzog, H., Steinmetz, H., & Seitz, R. J. (1999). The neural circuitry involved in the reading of German words and pseudowords: A PET study. *Journal of Cognitive Neuroscience*, *11*, 383–398.
- Harasty, J., Double, K. L., Halliday, G. M., Kril, J. J., & McRitchie, D. A. (1997). Language-associated cortical regions are proportionally larger in the female brain. *Archives of Neurology*, *54*, 171–176.
- Hinojosa, J. A., Martín-Loeches, M., Gómez-Jarabo, G., & Rubia, F. J. (2000). Common basal extrastriate areas for the semantic processing of word and pictures. *Clinical Neurophysiology*, *111*, 552–560.
- Hjorth, B. (1975). An on-line transformation of EEG scalp potentials into

- orthogonal source derivations. *Electroencephalography and Clinical Neurophysiology*, 39, 526–530.
- Hjorth, B. (1980). Source derivation simplifies topographical EEG interpretation. *American Journal of EEG Technology*, 20, 121–132.
- Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*, 30, 47–61.
- Holcomb, P. J., & McPherson, W. B. (1994). Event-related brain potentials reflect semantic priming in an object decision task. *Brain and Cognition*, 24, 259–276.
- Jacobs, B., Schall, M., & Cheibel, A. B. (1993). A quantitative dendritic analysis of Wernicke's area in humans. II. Gender, hemispheric, and environmental factors. *Journal of Comparative Neurology*, 327, 97–111.
- Kuriki, S., Takeuchi, F., & Hirata, Y. (1998). Neural processing of words in the human extrastriate visual cortex. *Cognitive Brain Research*, 6, 193–203.
- Kutas, M. (1997). Views on how the electrical activity that the brain generates reflects the functions of different language structures. *Psychophysiology*, 34, 383–398.
- Lehmann, D. (1987). Principles of spatial analysis. In A. S. Gevins, & A. Rémond (Eds.), *Handbook of electroencephalography and clinical neurophysiology: Revised series, Vol. 1. Methods of analysis of brain electrical and magnetic signals* (pp. 309–354). Amsterdam: Elsevier.
- Lüders, H., Lesser, R. P., Hahn, J., Dinner, D. S., Morris, H. H., Wyllie, E., & Godoy, J. (1991). Basal temporal language area. *Brain*, 114, 743–754.
- Mangun, G. R., & Hillyard, S. A. (1995). Mechanisms and models of selective attention. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 40–85). Oxford, UK: Oxford University Press.
- Martín-Loeches, M., Hinojosa, J. A., Gómez-Jarabo, G., & Rubia, F. J. (1999). The recognition potential: An ERP index of lexical access. *Brain and Language*, 70, 364–384.
- McCarthy, G., Nobre, A. C., Bentin, S., & Spencer, D. D. (1995). Language-related field potentials in the anterior medial temporal lobe: I. Intracranial distribution and neural generators. *Journal of Neuroscience*, 15, 1080–1089.
- McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, 62, 203–208.
- Menard, M. T., Kosslyn, S. M., Thompson, W. L., Alpert, N. M., & Rauch, S. L. (1996). Encoding words and pictures: A positron emission tomography study. *Neuropsychologia*, 34, 185–194.
- Mesulam, M. M. (1998). From sensation to cognition. *Brain*, 121, 1013–1052.
- Nigam, A., Hoffman, J. E., & Simons, R. F. (1992). N400 to semantically anomalous pictures and words. *Journal of Cognitive Neuroscience*, 4, 15–22.
- Nobre, A. C., Allison, T., & McCarthy, G. (1994). Word recognition in the human inferior temporal lobe. *Nature*, 372, 260–263.
- Nobre, A. C., Allison, T., & McCarthy, G. (1998). Modulation of human extrastriate visual processing by selective attention to colours and words. *Brain*, 121, 1357–1368.
- Oken, B. S., & Chiappa, K. H. (1986). Statistical issues concerning computerized analysis of brainwave topography. *Annals of Neurology*, 19, 493–494.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97–113.
- Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 171–216). Oxford, UK: Oxford University Press.
- Pernier, J., Perrin, F., & Bertrand, O. (1988). Scalp current density fields: Concept and properties. *Electroencephalography and Clinical Neurophysiology*, 69, 385–389.
- Petersen, S. E., Fox, P. T., Posner, M. I., Mintum, M., & Raichle, M. E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature*, 331, 585–589.
- Petersen, S. E., Fox, P. T., Snyder, A. Z., & Raichle, M. (1990). Activation of extrastriate and frontal cortical areas by visual words and word-like stimuli. *Science*, 249, 1041–1044.
- Posner, M. I., & Pavese, A. (1998). Anatomy of word and sentence meaning. *Proceedings of the National Academy of Sciences of the United States of America*, 95, 899–905.
- Price, C. J. (1997). Functional anatomy of reading. In R. S. J. Frackowiak, K. J. Friston, C. D. Frith, R. J. Dolan, & J. C. Mazziotta (Eds.), *Human brain function* (pp. 301–328). San Diego: Academic Press.
- Rubin, G. S., & Turano, K. (1992). Reading without saccadic eye movements. *Vision Research*, 32, 895–902.
- Rudell, A. P. (1991). The recognition potential contrasted with the P300. *International Journal of Neuroscience*, 60, 85–111.
- Rudell, A. P. (1992). Rapid stream stimulation and the recognition potential. *Electroencephalography and Clinical Neurophysiology*, 83, 77–82.
- Rudell, A. P. (1999). The recognition potential and the word frequency effect at a high rate of word presentation. *Cognitive Brain Research*, 8, 173–175.
- Rudell, A. P., Cracco, R. Q., Hassan, N. F., & Eberle, L. P. (1993). Recognition potential: Sensitivity to visual field stimulation. *Electroencephalography and Clinical Neurophysiology*, 87, 221–234.
- Rudell, A. P., & Hua, J. (1995). Recognition potential latency and word image degradation. *Brain and Language*, 51, 229–241.
- Rudell, A. P., & Hua, J. (1996a). The recognition potential and conscious awareness. *Electroencephalography and Clinical Neurophysiology*, 98, 309–318.
- Rudell, A. P., & Hua, J. (1996b). The recognition potential and word priming. *International Journal of Neuroscience*, 87, 225–240.
- Rudell, A. P., & Hua, J. (1997). The recognition potential, word difficulty, and individual reading ability: On using event-related potentials to study perception. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 1170–1195.
- Rugg, M. D., & Coles, M. G. H. (1995). The ERP and cognitive psychology: Conceptual issues. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 27–39). Oxford, UK: Oxford University Press.
- Salmelin, R., Service, E., Kiesila, P., Uutela, K., & Salonen, O. (1996). Impaired visual word processing in dyslexia revealed with magnetoencephalography. *Annals of Neurology*, 40, 157–162.
- Scherg, M. (1990). Fundamentals of dipole source potential analysis. *Advances in Audiology*, 6, 40–69.
- Scherg, M. (1992). Functional imaging and localization of electromagnetic brain activity. *Brain Topography*, 5, 103–111.
- Scherg, M., & Berg, P. (1991). Use of prior knowledge in brain electromagnetic source analysis. *Brain Topography*, 4, 143–150.
- Sereno, S. C., Rayner, K., & Posner, M. I. (1998). Establishing a time-line in word recognition: Evidence from eye movements and event-related potentials. *NeuroReport*, 9, 2195–2200.
- Sergent, J., Ohta, S., & MacDonald, B. (1992). Functional neuroanatomy of face and object processing: A positron emission tomography study. *Brain*, 115, 15–36.
- Skrandies, W. (1998). Evoked potential correlates of semantic meaning—A brain mapping study. *Cognitive Brain Research*, 6, 173–183.
- Thompson-Schill, S. L., Aguirre, G. K., D'Esposito, M., & Farah, M. J. (1999). A neural basis for category and modality specificity of semantic knowledge. *Neuropsychologia*, 37, 671–676.
- Tootell, R. B. H., Dale, A. M., Sereno, M. I., & Malach, R. (1996). New images from human visual cortex. *Trends in Neurosciences*, 19, 481–489.
- Tranel, D., Damasio, H., & Damasio, A. R. (1997). A neural basis for the retrieval of conceptual knowledge. *Neuropsychologia*, 35, 1319–1327.
- Vandenberghe, R., Price, C., Wise, R., Josephs, O., & Frackowiak, R. S. (1996). Functional anatomy of a common semantic system for words and pictures. *Nature*, 383, 254–256.

(RECEIVED June 24, 1999; ACCEPTED February 14, 2000)