The recognition potential and repetition effects

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Abstract

The recognition potential (RP) is an electrical brain response peaking at 250 ms that appears when subjects view meaningful stimuli. Previous RP research was conducted in experimental conditions in which repetition effects could not be totally ruled out as influencing the generation of the RP response. The present study aims to elucidate whether repetition effects affect the topography and waveform of this component. For this purpose semantically correct, orthographically correct, strings of random letters, control and background stimuli were presented to 20 subjects following the rapid stream stimulation procedure and without repetition of any test stimulus. As previously, the RP showed its maximal amplitude at the PO7 electrode. It showed sensitivity to all levels of lexical processing, its response being maximal for semantically correct stimuli, and its topographical distribution was similar for all types of stimulus. Direct statistical comparisons with the data of a previous study where repetition effects could not be disregarded were performed, confirming the similarity between the results obtained in both experiments. The neural generators of the RP were placed again, as in previous studies, within the lingual gyrus. Although repetition effects have been reported to affect other semantic-related components such as the N400, they do not seem to affect either the topography or the waveform of the RP. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The recognition potential (RP) is an electrical brain response peaking between 200 and 250 ms after subjects view recognizable visual stimuli such as words or pictures (Rudell, 1990; Rudell et al., 1993; Martín-Loeches et al., 1999; Hinojosa et al., 2000). The RP is evoked using a stimulation method developed by Rudell (1992) called 'rapid stream stimulation' which consists of presenting stimuli at a very high rate (between 4 and 10 Hz). During this stimulation procedure, recognizable images are occasionally presented in a stream of

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non-recognizable images basically composed of randomly chosen parts of recognizable images. This method of stimulation greatly attenuates responses other than RP.

Several task manipulations seem to affect the RP latency in various ways. In this regard, degrading image quality (Rudell, 1991; Rudell and Hua, 1995; Martín-Loeches et al., 1999), increasing word difficulty (Rudell and Hua, 1997; Rudell, 1999) or presenting letters in a reversed way (Rudell et al., 2000), lead to an increase in its latency. However, its latency decreases when a prime stimulus is presented before target stimuli (Rudell and Hua, 1996a) and in those subjects who show better reading abilities (Rudell and Hua, 1997). However, factors like the number of syllables of a word or the number of repeated letters in a word have minor effects on RP latency (Rudell, 1999). Finally, it should be mentioned that selective attention is important when evoking RP responses since only the attended language evoked an RP when Chinese and English words were presented simultaneously to subjects who spoke both languages (Rudell and Hua, 1996b).

RP responses have been reported even to stimuli devoid of meaning, including legal pseudowords and strings of letters (Martín-Loeches et al., 1999, 2001a). However, the amplitude of the RP evoked by both legal pseudowords and strings of letters is significantly diminished as compared to that evoked by words. These results lead us to the conclusion that the RP does not reflect all-or-nothing processes but a gradual response to the different psycholinguistic levels (Martín-Loeches et al., 1999). This is an interesting finding if we take into consideration that the traditionally semantic-related component, the N400, peaks approximately 150 ms later than the RP does. In whatever case, both components might be reflecting different aspects of semantic processing occurring at different stages. At this regard, the RP seems a more appropriate candidate to be reflecting lexical selection processes, whereas the N400 would more likely be reflecting post-lexical processes (Chwilla et al., 1995; Weckerly and Kutas, 1999; Hinojosa et al., 2000).

The RP displays its maximal amplitude at parieto-occipital areas. The application of the Brain Electrical Source Analysis (BESA) algorithm (Scherg 1990) revealed that the neural generators of the RP are located in the lingual/fusiform gyrus, more precisely in its medial portion (Hinojosa et al., 2000; Martín-Loeches et al., 2001a). The implication of both lingual and fusiform gyri in semantic processing has been stated by numerous MEG, PET and fMRI studies (Binder et al., 1997; Kuriki et al., 1998; Büchel et al., 1998; Chee et al., 1999; Murtha et al., 1999), although the specific involvement of these areas on such processes is still unclear (Hagoort et al., 1999).

All these RP findings, however, have been obtained in experimental conditions in which repetition effects could not be fully discarded as presenting some influence in the generation of the RP response. At this regard each of the stimuli was repeated within each recording session by sixteen (Martín-Loeches et al., 1999), eight (Hinojosa et al., 2001), or four times (Martín-Loeches et al., 2001a). This situation leads to question whether stimulus repetition effects might be in part responsible of the differences in amplitude that have been found for the RP between different types of stimuli.

Previous data from some experiments that dealt with similar processes or where repetition effects could be to some extent tested suggest, nevertheless, that the RP amplitude appears to be insensitive to repetition effects. At this regard, neither familiarity (Rudell and Hua, 1997; Rudell, 1999) nor word priming (Rudell and Hua 1996a) affected the RP amplitude or its waveshape, even when the priming word was the same as the test word. Moreover, in one of our previous studies (Martín-Loeches et al., 1999) RP amplitude and differential amplitude values of the RP evoked by different levels of linguistic processing did not differ between experiment 1 and 2, although the degree of repetition of the stimuli largely differed between both experiments. Finally, it should be mentioned that repetition effects differ according to stimulus type, affecting differentially the topography of the components (Doyle et al., 1996; Rugg et al., 1997; Radeau et al., 1998). At this regard, the repetition of words and legal non-

words shows repetition effects, but no such effects have been found using unpronounceable non-words (Rugg et al., 1995; Rugg and Nagy, 1987). Interestingly, the topography of the RP has been identical across type of stimulus in all our previous studies, including that of unpronounceable non-words, so that at least the topography of the RP does not seem to be affected by repetition effects across type of stimulus (Martín-Loeches et al., 1999; Hinojosa et al., 2000; Martín-Loeches et al., 2001a).

However, all of these are indirect evidences that repetition effects could not affect either the RP amplitude or its waveform, so that this assertion cannot be firmly stated. The present study aims to elucidate this question, whether repetition effects affect the amplitude and topographical distribution of the RP. For this purpose we presented words, pseudowords and strings of letters that did not repeat along the experimental session to 20 subjects and compared the results with those obtained in a previous experiment with a similar design but in which each stimulus was repeated four times (Martín-Loeches et al., 2001a).

2. Materials and methods

2.1. Subjects

Twenty subjects (15 females), ranging in age from 20 to 26 (mean = 21.6), participated as volunteers in the experiment. All of them had normal or corrected-to-normal vision. All participants were right-handed, with average handedness scores (Oldfield, 1971) of +0.82, ranging from +0.44 to +0.100. Subjects were paid for participating in this experiment.

2.2. Stimuli

The same five types of stimulus used in the experiment of Martín-Loeches et al. (2001a) were used here. With the aim of replicating these stimulation procedures, there were pools of words (semantically correct stimuli, SC), pseudowords (orthographically correct stimuli, OC), and strings

of random letters that did not follow Spanish orthographic rules and were unpronounceable (RL). Pools of control (CN) and background (BK) stimuli were also used (see bellow). The pool of SC stimuli were further subdivided into two pools of 40 names of animals, used as targets (termed as SCt) and 40 names other than animals (termed as SCn-t, for SC non-targets). According to the Alameda and Cuetos (1995) dictionary of frequencies for Spanish both pools were of comparable familiarity (mean 19.9 for SCt, 23.5 for SCn-t, t_{78} = -0.45, $P > 0.1$) Moreover, they have also a comparable familiarity with the SCt and SCn-t stimuli presented in Martín-Loeches et al. (2001a) experiment ($F_{3,116}$ = 0.7; $P > 0.1$) as an ANOVA comparing the four means demonstrated (26.4 for SCt and 32.7 for SCn-t, in the experiment of Martín-Loeches et al., 2001a). Pools of OC, RL and CN stimuli were also composed of 40 stimuli each, whereas the BK one included 80 stimuli.

Stimuli included in SCt and SCn-t pools were two-syllabled Spanish words which could be formed by five (80% within each pool), four (10%) or six (10%) letters. The OC pool was selected on the basis of a previous study with a Spanish population (García-Albea et al., 1982). It was composed of two-syllabled pseudowords, i.e. strings of letters that follow orthographic and phonological rules but with no meaning, the number of letters following the same distribution as the SC stimuli. The RL stimuli were strings of four, five and six letters again according to the same percentages of SC and OC stimuli, formed by randomizing the letters of SCt words. These strings of letters did not follow neither orthographic nor phonological rules. The CN stimuli were made by cutting SCt stimuli in 'n' portions ('n' being the number of letters that composed a word, minus one). The portions were replaced, always following the same rules: the first piece of the word was placed on 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 by this way had at least two complete letters but also clearly identifiable non-letters (formed by the joining of different letter fragments). Finally, the pool of BK stimuli was composed of the same 40 CN

CISNE	SEMANTICALLY CORRECT (TARGET)
PANEL	SEMANTICALLY CORRECT (NON-TARGET)
VADRO	ORTHOGRAPHICALLY CORRECT
MROEB	RANDOM LETTERS
3ORFИB⁄	CONTROL
⊃A3⊃:M⟨	BACKGROUND

Fig. 1. Examples of the stimulus images presented to subjects.

stimuli together with a new set of 40 stimuli made in the same way that CN stimuli except that portions were replaced randomly. Fig. 1 displays examples of each type of stimulus.

All the stimuli were 1.3 cm in height and 3.5 in width and were equated in visual aspects and overall physical attributes. The subjects' eyes were 65 cm from the screen. Images were 1.14° high and 3° wide in their visual angles at that distance. All the stimuli were presented white-on-black on a NEC computer MultiSync monitor, controlled by the Gentask module of the STIM package (NeuroScan Inc).

The only difference between stimuli presented in Martín-Loeches et al. (2001a) and those in present experiment is that the former were sprinkled within a rectangle of random dots in order to equate physical attributes. The presence of this mask would only cause a delay in the RP latency (Rudell and Hua, 1995), this not being an important parameter in repetition effects research (Rugg et al., 1997, 1998).

2.3. Procedure

Rapid stream stimulation procedure (Rudell 1992) was used. The computer displayed mostly BK stimuli, and after six or seven BK (this number randomized) a test stimulus was presented. Test stimuli could be SCt, SCn-t, OC, RL or CN. Stimuli were displayed with a stimulus onset asynchrony (SOA) of 257 ms.

An experimental session consisted of eight sequences of stimuli with duration of approximately

55 s each. A sequence started with six or seven BK stimuli, determined by a random process, followed by the first test stimulus. Also a random process determined the type of stimulus applied with the constriction of no more than two of the same type could appear consecutively. Each sequence contained 5 SCt, 5 SCn-t, 5 OC, 5 RL, and 5 CN stimuli, together with the proportional amount of BK stimuli. Test stimuli could never be repeated during an experimental session. Sequences were randomized for each subject.

Subjects were instructed to press a button as fast as possible every time they detected a word corresponding to an animal name (SCt). At the beginning of every sequence subjects had to push the button and a message appearing in the screen noticed them that they should blink as much as they wanted (they were told to avoid blinking as much as possible during stimulus presentation) and push again for starting the sequence. At the end of each sequence, feedback about their performance was provided to the subjects.

2.4. Electrophysiological recordings

An electrode cap (ElectroCap International) with tin electrodes was used for recording Electroencephalographic (EEG) data. 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 on the left mastoid (M1) were originally referenced to one electrode at the right mastoid (M2). The electrooculogram (EOG) was obtained from electrodes placed on forehead and near the outer cantus of the left eye (vertical EOG) and the left vs. right lateral orbital rim. A commercial skin preparation and an electrode paste produced impedances below 3 kΩ.

A bandpass of 0.3–100 Hz (3dB points for −6dB/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 sequence. The buffers were stored in a file along with other relevant information, such as the number of trials of each type.

2.5. Data analysis

The continuous recording was divided into 1024 ms epochs beginning from the onset of every test stimulus. Those epochs including artifacts exceeding ± 65 µV were automatically rejected. Additionally, a visual inspection was performed and trials in which there were no responses to SCt, or the RT was not between 200 and 800 ms were excluded. Also, trials containing false alarms were excluded. ERP averages were categorized according to each type of stimulus.

Originally M2-referenced data were algebraically re-referenced off-line using the averaged reference method (Lehmann, 1987) for the whole sample of cephalic electrodes. This method has probed to be the best way to obtain the RP (Martín-Loeches et al., 2001a). The topography of the RP, and both its peak latency and its amplitude were measured from average waveforms in the 160–417 interval after test image onset, following criteria outlined elsewhere (Rudell and Hua, 1997).

The brain electrical source analysis (BESA) algorithm (Scherg, 1990) was applied in order to elucidate the neural generators of the RP and compare them with those obtained in our previous study (Martín-Loeches et al., 2001a). We used the approach of locating vertically oriented dipoles at the center of the sphere (neutral position and orientation) and let the program automatically fit both the position and the orientation. The acceptable value of explained variance was over 90% (Scherg, 1992).

3. Results

3.1. Performance

There were 4000 epochs (40 of each of five types of stimulus in 20 subjects) and 1.5% were excluded because eye blinks were detected. An additional 0.65% was rejected due to premature or late responses. Also those trials with omissions and false alarms were excluded, which represented a 2.2% and a 2.3%, respectively. Mean reaction time was 558 ms.

3.2. Electrophysiology

After subtracting the responses for control trials from each of those elicited by SCt, SCn-t, OC, and RL trials in order to eliminate driving and enhance language-related factors, a negative wave peaking maximally at PO7 was obtained. Amplitude and peak latency values were −4.7 µV and 252 ms for SCt, −4 µV and 252 ms for SCn-t, −3.3 µV and 248 ms for OC, and −2.6 µV and 252 ms in the case of RL stimuli. These measures seem similar to those reported in our previous experiment (−4.5 µV and 268 ms for SCt, −3.8 µV and 276 ms for SCn-t, −2.4 µV and 272 ms for OC, and −1.9 µV and 268 ms in the case of RL stimuli. The amplitude was also maximal at PO7 electrode for all the stimuli with the exception of RL that displayed its highest amplitude at PO8 electrode). The grand-mean average waves corresponding to every type of stimulus after subtracting the responses for control trials are displayed at Fig. 2 for PO7 and PO8 electrodes.

An ANOVA comparing RP peak latencies across all types of stimulus at PO7 electrode yielded non-significant results ($F_{4,76} = 0.2$, $P > 0.1$). Therefore, the same peak latency could be assumed across types of stimulus. Regardless of the time of stimulus, a narrow window was established centered on the overall mean peak amplitude (approx. 252 ms) with the purpose of measure amplitude for statistical analysis. This window went from 224 to 280 ms (mean ± 28) after stimulus onset.

The maps of the average referenced activity in the 224–280-ms period for each type of stimulus are displayed in Fig. 3. Once again, activity evoked by CN stimuli was subtracted from each of the waveforms to make maps. As can be noticed the four maps show a very similar topography. It basically consists in a bilateral inferior parieto-
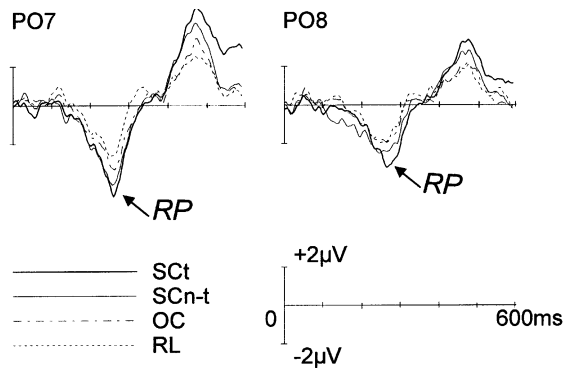
Fig. 2. Absolute grand average waveforms after subtracting control trials from each of the waveforms for each type of stimulus at PO7 and PO8 electrodes. A clear recognition potential (RP) can be identified for all types of stimulus (SCt, SCn-t, OC and RL, respectively), being higher in the case of target words. The RP amplitude was maximal at PO7. The latency was approximately 252 ms.

occipital (PO7, PO8) negativity, together with a positive activity of lower intensity over frontal and frontopolar. It can be also noticed that RP amplitudes are very similar for SCt and SCn-t stimuli, whereas they decrease for OC and RL stimuli.

Statistical analyses on amplitude were planned and performed on a selected sample of 30 out of the 60 total number of electrodes with the aim of avoiding an unacceptable degree of loss of statistical power due to the use of the high number of electrodes (Oken and Chiappa, 1986). 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 three-way ANOVA was performed on the mean amplitude along the 224–280 ms window with three repeated-measures factors: Type of stimulus as a factor which could exhibit one of five levels (SCt, SCn-t, OC, RL, or CN); Electrode, which included fifteen levels, and Hemisphere, with two levels.

Significant results were obtained for Type of stimulus ($F_{4,76} = 4.4$; $P < 0.01$), Electrode ($F_{14,266} = 81.7$; $P < 0.0001$); Hemisphere ($F_{1,19} = 10.2$; $P < 0.01$), and the interaction Type of stimulus × Electrode × Hemisphere ($F_{56,1064} = 5$; $P < 0.05$).

Post-hoc analyses with the Bonferroni correction were then performed only in those electrodes that showed the maxima RP values at each electrode across Type of stimulus, i.e. PO7 and PO8. Only the comparison between SCt and SCn-t did not differ ($F_{1,19} = 1.7$; $P > 0.1$). Apart from this, each type of stimulus was significantly different when compared with each other at PO7 ($75.1 > F_{1,19} > 5.7$; $P < 0.0001$ in all cases, with the exception of SCn-t vs. OC and OC vs. RL, both with $P < 0.05$). At PO8 the comparisons between SCt and SCn-t stimuli again yielded no significant results, as much as the comparison of OC stimuli with RL stimuli. All the remaining comparisons at PO8 resulted significant ($48.4 > F_{1,19} > 8.1$; $P < 0.0001$ in all cases with the exception of SCt vs. OC, SCt vs. RL, SCn-t vs. OC, and SCn-t vs. RL, all with $P < 0.05$). Therefore, statistical analyses supported the existence of amplitude differences across types of stimulus at both hemispheres.

The maps in Fig. 3 display some degree of laterality. The Type of stimulus × Electrode × Hemisphere significant interaction supports this assertion. In order to elucidate this finding pairwise PO7 vs. PO8 comparisons were made for each type of stimulus, again with the Bonferroni correction. Similarly to our previous research (Martín-Loeches et al., 2001a), no PO7-PO8 comparison yielded significance [$4.18 > F_{1,19} > 0.13$; $P > 0.05$ in all cases]. Hence, and in order to enhance the apparent lateralities, the activity to CN stimuli was subtracted from each of the other types of stimuli (the same procedure applied in Martín-Loeches et al. (2001a)). Now, PO7 presented significantly larger RP amplitude in SCt ($F_{1,19} = 9.1$; $P < 0.05$), SCn-t ($F_{1,19} = 10.8$; $P < 0.05$), and OC stimuli ($F_{1,19} = 4.7$; $P < 0.05$). Thus, statistical analyses confirmed the existence of amplitude differences between hemispheres with the exception of RL stimuli, which would be in agreement with the maps in Fig. 3.

In order to fully compare present results with those in Martín-Loeches et al. (2001a) it was necessary to apply a profile analysis to test possible different scalp distributions across type of stimulus (McCarthy and Wood, 1985). Mean amplitudes in the 224–280-ms window were scaled for each subject across all electrodes, with the average distance from the grand mean ERPs, as denominator.
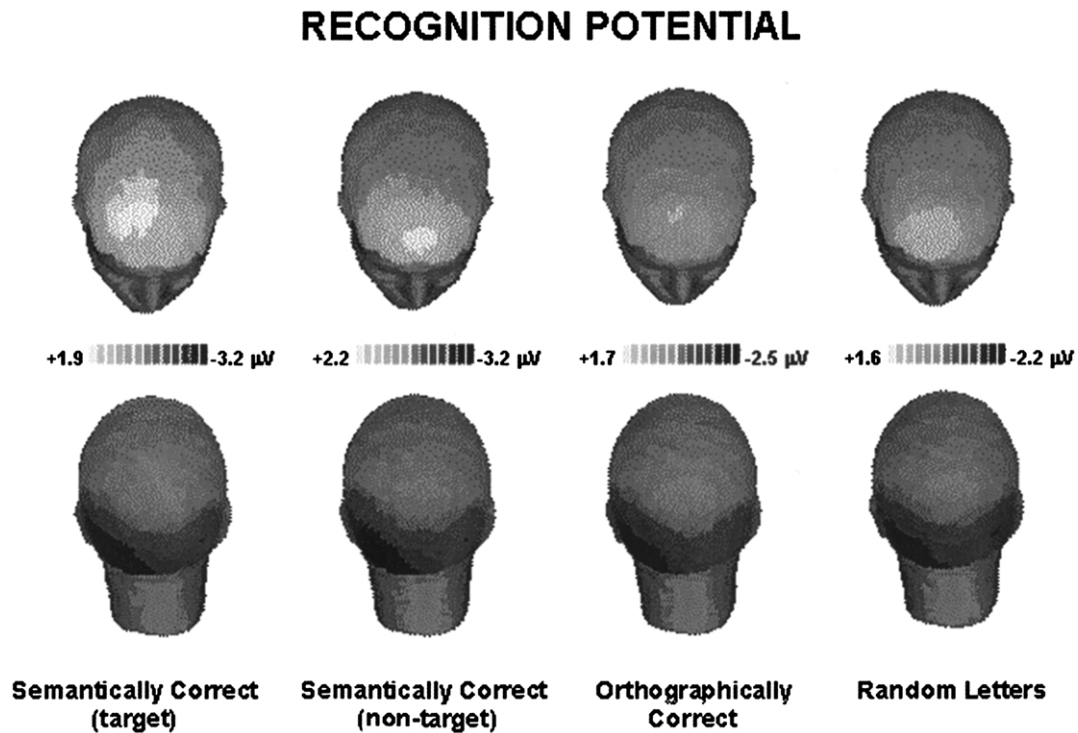
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Fig. 3. Topographic maps of the RP distribution across the total array of 60 cephalic electrodes. They represent mean values for the period 224–280 ms. Again, activity to control stimuli has been subtracted from each of the waveforms to make the maps. Note that individual color scales for amplitude values have been used. The topography of all the maps appears notably similar consisting of an inferior parieto-occipital negativity that was left-lateralized. Also lower amplitude positivity over the frontal and frontopolar regions can be observed.

An ANOVA was performed on these scaled data with Type of stimulus (four levels: SCt, SCn-t, OC and RL) and Electrode (30, since they were not dissociated by hemisphere). No significant differences were obtained in the Type of stimulus $\times$ Electrode interaction ($F_{87,1653} = 1$; $P > 0.1$). Post-hoc ANOVAs comparing every type of stimulus with each other with the purpose of increasing the power of profile analyses yielded no significant results again ($1.6 > F_{29,551} > 0.55$; $P > 0.1$ in all cases). Hence, the same neural generators could be assumed for all types of stimulus.

Applying criteria outlined elsewhere (Martín-Loeches et al., 2001a; Hinojosa et al., 2000), automatic fitting procedure of BESA dipoles was applied, assuming two dipoles that followed the constraint of being placed at mirror positions and present mirror orientations. This was applied only

to SCt data, since the assumption of same generators across types of stimulus made unnecessary to test dipole solutions for the other types of stimulus. Previous to the dipole analysis, current source density maps (Pernier et al., 1988) were performed (not shown), which revealed the existence of two sources, one near PO7 and the other near PO8. The counterpart activity was located over midline parietal regions. This indicates that frontal activity observed in topographical maps can be disregarded as a counterpart of posterior negativities. Thereafter, the dipole analysis was performed. It showed that the best position for the neural generators of the RP component was near the lingual gyrus, which explained 97.3% of the variance. Position, orientation and source waveforms (magnitude over time) of this dipole position are displayed in Fig. 4. This dipole solu-
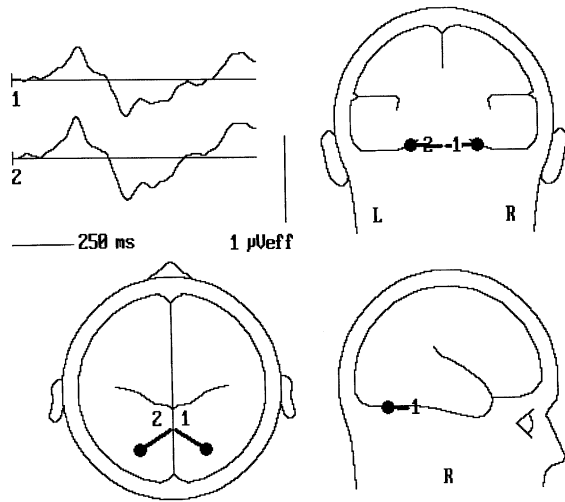
Fig. 4. Positions of the two dipoles for the RP evoked by semantically correct target stimuli. Numbers identifying each dipole are located near the sharp end of the vector representing their orientation. That is, dipole number 1 is located within the left hemisphere whereas number 2 is within the right hemisphere. They conformed the best-fit solution found for the 224–280 ms time range and their location corresponds to the lingual gyrus. They are based on the waves for SCt stimuli after subtracting the activity to control stimuli.

tion largely coincides with that obtained in our previous studies (Hinojosa et al., 2000; Martín-Loeches et al., 2001a), making the neurophysiological approach to fit the dipole unnecessary.

Although all abovementioned results clearly replicate those reported in the experiment of Martín-Loeches et al. (2001a), further statistical analyses were performed in order to directly compare the results of the 20 subjects who participated in this experiment with those of the 21 subjects who participated in our previous experiment. An ANOVA was first conducted in order to compare latencies in both experiments including Type of stimulus as a within-subjects factor and a between-subjects factor, Repetition effects (two levels: Presence–Absence). Significant results were obtained for Repetition effects factor ($F_{1,39} = 8.2$; $P < 0.05$) but not for the Type of stimulus factor ($F_{3,117} = 0.38$; $P > 0.1$) nor for its interaction with Repetition effects factor ($F_{3,117} = 0.41$; $P > 0.1$). This is in consonance with differences in latency measures reported for both experiments,

and is most probably due to the presence of the sprinkled rectangle on the stimuli of our previous experiment, rather than to real repetition effects. In any case, as mentioned, latency has not seemed to be modulated as a consequence of repetition effects in previous research.

An ANOVA was performed on amplitude data. There were three within-subjects factors: Type of stimulus (five levels), Electrode (15 levels) and Hemisphere (two levels), and a between-subjects factor: Repetition effects (two levels). This yielded significant results in Type of stimulus ($F_{4,156} = 12.6$; $P < 0.0001$), Electrode ($F_{14,546} = 151.7$; $P < 0.0001$), Hemisphere ($F_{1,39} = 16.9$; $P < 0.0001$), Type of stimulus × Electrode ($F_{56,2184} = 49.3$; $P < 0.0001$), Type of stimulus × Hemisphere ($F_{4,156} = 10.4$; $P < 0.0001$), and Type of stimulus × Electrode × Hemisphere ($F_{56,2184} = 6$; $P < 0.0001$). A trend was observed in Electrode × Hemisphere interaction ($F_{14,546} = 2.47$; $p = 0.7$). These results largely coincide with those obtained individually in both Martín-Loeches et al. (2001a) and present experiments. It should be remarked that no influence of the Repetition effect factor was observed with the exception of two statistical trends in the Type of stimulus by Electrode × Repetition effects ($F_{56,2184} = 1.9$; $p = 0.8$) and Type of stimulus × Hemisphere × Repetition effects ($F_{4,156} = 2.3$; $p = 0.7$) interactions.

The existence of these trends lead us to perform further analyses comparing the amplitudes evoked by stimuli presented in both experiments in a particular condition at PO7 and PO8 electrodes. This decision was taken since a detailed inspection of the topographical maps revealed that a difference in lateralization could exist when comparing OC and RL stimuli in present experiment with OC and RL stimuli in Martín-Loeches et al. (2001a) experiments, thus being responsible of the reported trends. AVOVAs were therefore performed for each type of stimulus with Hemisphere (two levels: PO7 and PO8 electrodes) as a within-subject factor and Repetition effects (two levels: Presence–Absence) as a between-subject factor. These analyses yielded significant results for the Hemisphere factor in SCt ($F_{1,39} = 24.3$; $P < 0.0001$), SCn-t ($F_{1,39} = 20.6$; $P < 0.0001$), and OC ($F_{1,39} = 6.8$; $P < 0.05$) conditions, which is in

consonance with the left lateralization observed in the topographical maps for these conditions. Significant results were obtained in the Repetition effects factor only in OC ($F_{1,39} = 10.6$; $P < 0.05$), and RL ($F_{1,39} = 14.3$; $P < 0.05$) conditions which would match the differences observed in lateralization in the topographical maps of these conditions when comparing Martín-Loeches et al. (2001a) and present experiments. Whereas in the former, in which repetition effects were present, OC stimuli showed bilateral distribution and RL stimuli even were right lateralized, that was not the case of the present experiment. In this experiment, totally free of repetition effects, OC stimuli were left-lateralized whereas RL stimuli showed a bilateral distribution. No other significant results were observed neither for the Repetition effects factor ($2.2 > F_{1,39} > 1.6$; $P > 0.1$) nor for its interaction with the Hemisphere factor ($1.6 > F_{1,39} > 0.1$; $P > 0.1$).

4. Discussion

The results of present experiment replicated those obtained in previous RP research (Martín-Loeches et al., 1999; Hinojosa et al. 2000; Martín-Loeches et al., 2001a). These basically consisted of the finding of a negative response (the RP) to all levels of linguistic processing, including letter identification and orthographical analysis, that showed its highest values in response to stimuli with semantic content, and progressively diminishing as the level of linguistic processing decreases. These findings reinforce the importance of the RP as an index of lexical access and its highest sensitivity to semantic processing. Also, the neural generators displayed by the application of the BESA algorithm largely coincide with those obtained in previous studies, that is the medial portion of the lingual/fusiform gyri (Hinojosa et al., 2000; Martín-Loeches et al., 2001a,b). There are, however, latency differences between both experiments. As we mentioned in the materials and methods section, the absence of the mask for the stimuli in present as compared with the experiment by Martín-Loeches et al.

(2001a), complicates the interpretation of these results. In whatever case, the longer latency was measured when both mask and repetition of stimuli were present. The opposite pattern if any, could be expected, however, if repetition effects influence in some way the RP latency, that is the repetition of stimuli leading to a facilitation of their recognition. Thus the effects of the mask would be attenuated and latency measures equated with those obtained when stimuli are not repeated. As that was not the case, the results can easily be interpreted as the mask causing a latency delay without repetition effects on RP latency (Rudell and Hua, 1995). However, one should be cautious when interpreting these conclusions, as no direct measurement could be performed. For this reason, we will focus the attention of the discussion on RP amplitude and its topographical distribution, being these parameters basically those that have been actually observed to be modulated by repetition effects in previous research (Doyle et al., 1996; Rugg et al., 1998).

Previous research on repetition effects and ERPs shows evidence of these effects modulating mainly two long-latency, temporally and spatially overlapping components: the N400 and a late positive component associated to the P300 family (Rugg and Doyle, 1994). Although that was not always the case, a large proportion of this modulation has consisted in changes in their topographical distribution. At this regard, the late positive component becomes larger over the left hemisphere, and the N400 shows a right-greater-than-left asymmetry as a consequence of repetition effects (Doyle et al., 1996). Also, N400 amplitude becomes attenuated, whereas the late positive component amplitude becomes enhanced with repetition effects. Repetition effects have been seemed also to affect other long-latency responses. For instance, Rugg et al. (1998) found an enhanced positivity for repeated words when compared with new words between 300 and 500 ms after stimulus onset at frontal electrodes. More positive-going waveforms were also reported during the same period of time for old words when compared with new words at parietal electrodes.

Finally, it should be noticed that repetition effects affect in a distinct way words and pseudowords (Rugg et al., 1997).

An overall consideration of data reported here does not support the existence of modulations of neither the amplitude nor the topography of the RP attributable to repetition effects for those stimuli with semantic content. At this regard amplitude values and topographic distribution plainly coincide with those reported in our previous experiment. The same is true for their neural generators. There is only a subtle difference when comparing the results obtained here and those reported in Martín-Loeches et al. (2001a) in the case of stimuli with semantic content. Whereas in the later study significant amplitude differences between SCt and SCn-t stimuli were observed, this was not the case in present experiment. Some minor differences between the experimental designs might be responsible, at least partially. At this regard, the number of sequences was smaller in the present experiment, which could lead to relatively noisier recordings and, hence, to reduce the statistical power in the comparisons. Also the necessary increase of the number of stimuli belonging to the SCn-t pool in order to avoid repetitions in present study made this pool more heterogeneous. The areas that generate the RP might show some special sensitivity to certain aspects, such as visual semantic features according to recent findings (Murtha et al., 1999; Thompson-Schill et al., 1999; Martín-Loeches et al., 2001b). Animals, as well as other semantic categories including food and others, are categorized on the basis of their perceptual properties according to the sensory/functional theory (Warrington and McCarthy, 1987). In this sense, both target pools should not differ in these parameters between our present and previous study, as they were always animals. In the present study, however, as the number of stimuli belonging to the non-target semantically correct pool differs from that used in Martín-Loeches et al. (2001a) experiment, the proportion of words that are categorized according to their visual properties might differ between studies, which could be responsible at least in part of the decrease in the differences between SCt and SCn-t stimuli. It should be noticed, nev-

ertheless, that although they did not reach statistical significance, amplitude differences actually did exist between SCt and SCn-t stimuli (Fig. 2), these differences highly resembling those presenting statistical support in our previous study (see Fig. 2 in Martín-Loeches et al., 2001a). In whatever case, the remarkable finding is that SC stimuli amplitude and their topographic maps and neural generators were the same as in Martín-Loeches et al. (2001a), where repetition effects could be present.

In the case of OC and RL stimuli the situation is roughly different, as there are some subtle differences in lateralization between Martín-Loeches et al. (2001a) and present experiments. It appears therefore that the effects of the repetition of the stimuli on the RP affect stimuli devoid of meaning. However, this assertion is based on a statistical trend. Accordingly, it appears appropriate to consider it as a provisional one. To our knowledge, no study has reported modulation of unpronounceable strings of letters (our RL stimuli) as a consequence of repetition effects.

A few words should be finally devoted to discuss the possible role that the processes reflected by the RP play in the semantic processing as compared to those reflected by other semantic-related ERPs, as the N400. Provided that repetition effects are related to memory processes (Rugg et al., 1996), the insensitivity of the RP to these effects in the case of words, would indicate that this component is actually reflecting processes which are less based on memory than those processes reflected by the N400, that is actually affected by repetition effects. However, the RP latency coincides with the moment at which lexical access seems to take place, as revealed by eye motion studies that report fixation periods for words during reading of approximately 250 ms (Just and Carpenter, 1980; Sereno et al., 1998; Posner and Abdullaev, 1999). Accordingly, the RP would be reflecting word semantic processing along its occurrence. However, the N400 appears later and therefore the processes reflected by this component should be subsequent to this semantic access. The N400 would be dealing with other subsequent processes in which memory would be more notably involved, such as the integration of

word representations in current context or the inhibition of incompatible knowledge, as has been recently proposed by several authors (Weckerly and Kutas, 1999; Debruille, 1998).

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