PERGAMON

Neuropsychologia 39 (2001) 1086–1096

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Functional differences in the semantic processing of concrete and abstract words

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Received 24 January 2000; received in revised form 7 December 2000; accepted 12 February 2001

Abstract

There is considerable debate as to whether the semantic system is a unitary one in which meanings are available in a peculiar, perceptual-free format, or whether it is functionally segregated into anatomically discrete, modality-specific but semantic regions. In the former case, concrete and abstract words should not differ in the amount of activation of semantic areas. Neuroimaging studies in this field are, however, far from conclusive, and one reason for this may be that the degree of imageability of the stimuli — probably a crucial variable — has not been considered. Recognition Potential (RP) reflects semantic processing and appears to originate in basal extrastriate regions involved in semantic processing. In this study, we compared the RP of concrete and abstract words that actually differ in their degree of imageability. Results indicate that the semantic processing areas in which the RP originates display a higher activation for concrete (more imageable) material, but that abstract material also evokes a notably larger RP component compared with pseudowords or unpronounceable letter strings. Accordingly, the study appears to suggest that there is no full functional segregation of the semantic systems. Rather, our data support the existence of a semantic system that is specialised in concrete, imageable material, and that is also activated, though to a lower extent, by abstract material.

Keywords: ERPs; Recognition potential; Basal extrastriate; Imageability; Concreteness

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1. Introduction

Of the several brain regions that can be activated during tasks that require semantic processing, or even during passive perception of stimuli with a semantic content, only a few appear to be solid candidates to actually constitute the neural substrates of a conceptual or semantic processing system. Indeed, neuroimaging studies have yielded important discrepancies when attempting to delimit these highly specialised areas, the different results probably being attributable to secondary factors such as differences between studies in the technical equipment, the subjects tested or, more importantly, the cognitive tasks used [9]. Thus, only a certain number of the described areas should be finally accepted as related to semantic processing, the remainder probably reflecting the activity of other subsequent or auxiliary, though related, processes, such as attentional control, perceptual analyses, and so on.

Among the best candidates to constitute part of the semantic processing system of the brain are some portions of the basal extrastriate areas, which constitute what has been termed as the 'basal temporal language area', or even the 'third language area' [22]. These regions have been reported as the only ones that are consistently activated across studies of picture naming with PET [27]. It has also been established that these regions respond differentially to words and pseudowords or unpronounceable letter strings, though there is some disagreement in the literature as to which specific portion within the basal extrastriate areas complies with this description [7,13,20,28,36,43]. Moreover, those portions of the basal extrastriate areas subserving

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PII: S0028-3932(01)00033-1

semantic processing can be activated independently of the input modality [6,8], also appearing to be independent of arbitrary language signs, since they can be activated by either words or pictures [27,43].

However, it does not appear to be completely clear which kind of semantic format is subserved by these regions. Several models propose that the semantic system is a unitary one, common for every kind of processed information or item categorisation, and in which meanings are available in a peculiar, perceptual-free format [10,11]. Accordingly, these portions within basal extrastriate regions, as part of this semantic system, would be totally independent of the modality of the items processed. Other models, however, propose that this is not exactly the case. Rather, the semantic system would be functionally segregated into anatomically discrete, though highly interactive, modality-specific regions [42]. It is important to note, nevertheless, that in accordance with this latter point of view, semantic processes should not be confused with perceptual processing, even if they are to some extent modality dependent, since they would represent one step further. That is, we should not confuse input modality with semantic modality. In this regard, it has been specifically proposed that basal extrastriate regions are actually subserving some kind of visual-semantic or higher-level visual-perceptual (also termed 'structural') processing, even if they are activated by any type of input modality [27,42].

If this is the case and those portions within basal extrastriate regions belonging to the semantic processing system were to subserve some kind of visual semantic operations, it should be expected that the processing of abstract material does not activate these regions, or at least that it does so minimally in comparison to the processing of concrete material. However, the small number of neuroimaging studies directly comparing semantic processing of abstract and concrete material have drawn conclusions that are far from clear in this regard. In the study by Kiehl et al. [16] using fMRI, the fusiform gyrus, a main structure in which these basal extrastriate semantic regions appear to be located, was activated by either abstract or concrete words in a very similar manner. Interestingly, many other regions in addition to the fusiform gyrus were activated equally by either abstract or concrete words, with the exception of the right superior temporal gyrus. Therefore, this study would support a mainly unitary semantic system with a specialised part only for abstract material. By contrast, Beauregard et al. [4], using PET, reported a fusiform activation when subjects passively viewed concrete words, but not when they viewed abstract words. These authors also found several other areas that differed in their response to concrete and abstract materials, thus supporting a functional segregation of the semantic system. On the whole, however, results concerning the basal extrastriate regions, which for reasons outlined above would be substantiated as actually constituting part of the semantic processing system of the brain, appear to be conflicting.

ERP studies have also been performed, comparing electrical modulations for concrete and abstract words. [15,17,44]. However, the small number of electrodes used, together with an absence of source analyses, have limited their conclusions to a right-left or anterior-posterior distinction between concrete and abstract materials. Overall, ERP studies seem to support different systems for processing abstract and concrete materials, but no specific conclusions can be drawn from these studies regarding the basal extrastriate regions.

A factor that may underlie the discrepancies in the neuroimaging literature is the degree of imageability of the items to be processed. Indeed, although there is a commonsense tendency to identify the concrete-abstract dimension as equivalent to the imageable–non-imageable dimension, this appears not to be entirely true. In fact, concreteness (the degree to which a word refers to concrete objects) and imageability (a word's ability to evoke mental images) are highly correlated, but would constitute different factors [31,44]. It appears, therefore, that in the case that basal extrastriate regions do subserve visual semantic information or higher-level visual perceptual processing, abstract and concrete material should differ in the degree of implication of these areas only if they differ in their degree of imageability. Interestingly, however, although the neuroimaging studies mentioned above did control several important factors (such as word frequency, word length or word pleasantness) of their concrete and abstract material, this was not the case for the imageability factor. It appears, therefore, that when neuroimaging studies did not find abstract versus concrete words differences in basal extrastriate areas, this may plausibly be due to possible similarities between the two types of material in the imageability dimension. In fact, although concrete material is mostly imageable, abstract words present a high degree of variability within this dimension [2,31]. Accordingly, it remains to be clarified whether semantic processing within the basal extrastriate areas, which are among the best candidates to truly constitute part of the semantic processing system, differs between concrete and abstract words when stimulus imageability is taken into account.

Recognition Potential (RP) is an electrical response of the brain that is highly sensitive to the semantic content of stimuli, and that according to brain electrical source analysis algorithms would reflect activity generated within basal extrastriate areas [14,23,24,39]. Specifically, it appears that the neural generators of RP are located within the lingual and fusiform gyri [24]. Previous research has established that this electrical component would be generated by those portions within the basal extrastriate regions that constitute part of the semantic processing system [14,24]. This assertion is further reinforced by the selective sensitivity of this Event-Related Potential (ERP) to the same parameters to which these portions of the basal extrastriate areas are sensitive according to the haemodynamic and magnetoencephalographic literature. Hence, it displays its highest amplitude when the stimuli contain conceptual or semantic meaning, this holding true for either words or pictures [14,23,24,39]. Also, its time of appearance, with a peak between 250 and 300 ms after stimulus onset, makes it a better candidate to directly reflect semantic processing throughout its occurrence than other ERP components such as the N400.

In this study, we aimed to compare the RP obtained to both concrete and abstract words when explicitly checking their degree of imageability. Specifically, the RP obtained when using concrete words with a high degree of imageability will be compared with the RP for abstract words with low values in the imageability dimension, the two kinds of words significantly differing in this dimension. If the theories proposing that the semantic system is a unitary one devoid of any kind of perceptual or perceptual-like format were to hold, then the RP, a component reflecting the activity of regions that are among the best candidates to constitute part of this semantic system, should be identical for concrete and abstract materials that differ in their degree of imageability. If, on the other hand, certain semantic areas are actually subserving some kind of perceptual-semantic or higher-level perceptual processing, then the RP to concrete material should be different from the RP to abstract material. Considering the neural origin of the RP in basal extrastriate areas, and that these areas have been proposed as visual-semantic, the amplitude of the RP to concrete, more imageable stimuli should display significantly higher values than the RP to abstract material.

2. Methods

2.1. Subjects

Twenty subjects (10 females), ranging in age from 17 to 30 (mean = 22.2), 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 [30] of $+0.80$, ranging from $+0.38$ to $+0.100$.

2.2. Stimuli

There were pools of Semantically Correct (SC), Orthographically Correct (OC), Random Letters (RL), Control (CN), and Background (BK) stimuli. The SC stimuli were further divided into two pools of 20 concrete nouns and 20 abstract nouns. In order to distinguish the two pools, they will be termed SCc (for concrete SC), and SCa (for abstract SC). To harmonise them with SC stimuli, the pools for OC, RL, and CN stimuli were also of 20 elements each, whilst the BK pool comprised 40 stimuli.

Both the SCc and the SCa stimuli were Spanish words that could contain 5 (80% within each pool), 4 (10%) or 6 (10%) letters. According to the Alameda and Cueto [1] dictionary of frequencies for Spanish, the two pools of SC stimuli were of comparable frequency (mean 87.3 for SCc, 106.4 for SCa, $t_{38} = -0.54$, $P > 0.1$). According to the University of Valencia computerised word pool for Spanish [2], the two pools were also comparable in pleasantness (mean 4.2 for SCc, 3.5 for SCa, $t_{38} = 0.64$, $P > 0.1$). By contrast, and according to the latter normative study, the two SC pools differed significantly in the dimensions concreteness and imagery, which are of great relevance for the present work. The mean values in the concreteness dimension were 6.6 for SCc and 2.4 for SCa ($t_{38} = 55.3$, $P < 0.0001$), the former ranging between 6.51 and 6.87 and the latter between 1.88 and 2.86, 1.47 being the smallest score obtainable in this dimension and 6.87 the largest one. Mean values in the imagery dimension were 5.9 for SCc and 3.7 for SCa ($t_{38} = 8.9$, $P > 0.0001$), the former ranging between 5.68 and 6.54 and the latter between 2.69 and 5.11, 1.61 being the smallest score obtainable in this dimension and 6.71 the largest one. Spanish is a 'transparent' language, which means that all the words have regular orthographic-to-phonological mappings.

The OC stimuli consisted of non-words that followed phonological and orthographic rules for Spanish but were devoid of meaning, and did not approximate to or sound like any meaningful word. The number of letters followed the same percentages as for the SC stimuli. These OC words were selected on the basis of a previous study with a Spanish population [12]. The RL stimuli were non-words created by randomising half of the letters of both types of SC 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 half of each pool of SC words (randomly selected) in '*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 non-letters (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, but using the remaining words that were not selected to construct CN stimuli. Examples of each type of stimulus are displayed in Fig. 1.

All stimuli were 1.3 cm high and 3.5 cm wide. Subjects' eyes 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.).

2.3. Procedure

Rapid stream stimulation [37] was used. Accordingly, stimuli were displayed with an SOA of 257 ms. The computer displayed mostly BK stimuli. Periodically (after either six or seven BK, this number being randomised), a test stimulus instead of a background one was presented. The test stimulus could be SCc, SCa, OC, RL or CN. Stimulation was organised 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.

A total of 16 sequences were presented to each subject. Subjects were instructed to press a button every time they detected a word with meaning (i.e. either SCc or SCa). Subjects were told to respond as rapidly as possible. Each subject was presented with all of the stimuli from the pools. Each sequence contained 5 SCc, 5 SCa, 5 OC, 5 RL, and 5 CN stimuli, together with the proportional amount of background 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 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.

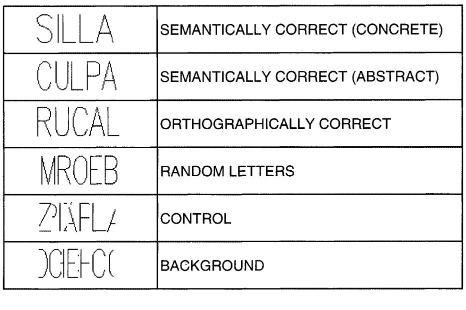

Fig. 1. Examples of the stimulus images presented to subjects. The English translation for the concrete semantically correct example (*silla*) is *chair*. The translation for *culpa* is *fault*.

After the recording sessions, the subjects were debriefed with a questionnaire on imagery and verbal habits and skills [33]. This test measures the extent to which a subject predominantly uses one or the other type of code (imagery vs. verbal) in cognitive operations, the usual result being to obtain an equivalent score in the two codes. This test is, therefore, of the highest interest for the present study in determining whether subjects are normal in this regard or there is a marked trend favouring one specific code in the sample.

2.4. 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 [3], 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 kΩ. 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 digitised 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.

2.5. Data analysis

The continuous recording was divided into 1024 ms epochs beginning from the onset of each SCc, SCa, OC, RL and CN type stimulus. Artifacts were automatically rejected by eliminating those epochs that exceeded ± 65 μV. A visual inspection was also carried out. Only correct trials were included in the analyses, also being excluded those in which RT was not between 200 and 800 ms. ERP averages were categorised according to each type of stimulus.

For the whole sample of cephalic electrodes, originally M2-referenced data were algebraically re-referenced off-line using the averaged reference method [21], which has proved to be the best way to obtain the RP [14,24]. Both latency and amplitude, together with the topography of the RP, were measured from average waveforms in the interval 160–417 ms after test image onset, following criteria outlined elsewhere [39].

The Brain Electrical Source Analysis (BESA) algorithm [41] was also used in order to elucidate the neural generators of the RP. This constituted a way of controlling whether the RP to concrete and abstract words is generated by the same structures already reported for the RP [14,24], and whether this holds regardless of type of stimulus. We used the approach of locating vertically-oriented dipoles at the centre of the sphere (neutral position and orientation) and let the program fit automatically both position and orientation.

3. Results

3.1. Performance

Of the 8000 trials (each of five types of stimulus, repeated five times for each one of 16 sequences in 20 subjects), 1.6% were excluded because eye blinks were detected. An additional 0.11% were excluded due to premature or late responses. Trials with omissions and false alarms were also excluded, which represented 0.86 and 1.68%, respectively. Mean reaction time was 504 ms for concrete nouns and 531 ms for abstract nouns, this difference being statistically significant ($t_{19} = -6.2$; $P < 0.0001$).

Mean scores obtained by subjects in the ‘questionnaire on imagery and verbal habits and skills’ were equated for the two codes ($t_{19} = 0.1$; $P > 0.1$), with 31.1 for the imagery code (range 20–38) and 30.2 for the verbal code (range 15–44).

3.2. Electrophysiology

Responses for control trials were subtracted from each of the waveforms in order to eliminate driving and enhance language-related factors. This yielded in the waves of both concrete and abstract words a negative component peaking maximally at PO7, with an amplitude of −4.9 μV and a peak latency of 272 ms for the former and of −4.3 μV and 268 ms for the latter. In the case of OC and RL stimuli, the amplitude was observed to be relatively similar at both PO7 and PO8 electrodes, though the highest values were again at PO7, showing an amplitude of −3.4 and −2.5 μV, respectively. Also, their peak latency was around 268 and 264 ms, respectively. Fig. 2 displays the grand-mean average waves in the PO7 and PO8 electrodes in all four types of stimulus. As mentioned previously, the responses for control trials were subtracted from each of the waveforms.

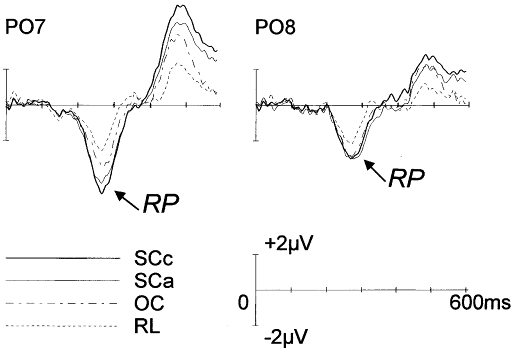

Fig. 2. Absolute grand average waveforms after subtracting control trials from each of the waveforms for each type of stimulus at PO7 and PO8 electrodes. A clear recognition potential (RP) can be identified for both concrete and abstract words (SCc and SCa, respectively), being higher in the case of concrete words. Orthographically correct stimuli (OC) and random letters (RL) also presented a reduced RP. The RP amplitude was maximum at PO7. The latency was around 268 ms.

An ANOVA was carried out considering the data at PO7 (that with the highest RP values), with the purpose of comparing peak latencies across the four types of stimulus. This yielded no significant differences between Type of stimulus ($F_{3,57} = 1.6$; $P > 0.1$). Therefore, we could assume the same peak latency for the RP to either type of stimulus.

Regardless of the type of stimulus, to measure amplitudes for statistical analyses and maps display, a narrow window was established centred on the overall mean peak amplitude (268 ms), and ranging from 240 to 296 ms (around mean ± 30) after stimuli onset.

The maps in the 240–296 ms period are displayed in Fig. 3. Again, activity to control stimuli has been subtracted from each of the waveforms to make the maps. It clearly appears that the topography of the four maps is very similar. This could be roughly described as a bilateral inferior parieto-occipital negativity, with a positive counterpart of lower intensity over frontal and frontopolar regions. There is also a subtle difference between types of stimulus, as there was a left-lateralised distribution of RP for both types of SC stimuli (see also Fig. 2), this left-lateralization also being present, but less marked, for OC and RL. Finally, RP amplitudes decrease progressively at PO7 from SCc to SCa, then from SCa to OC, and then from OC to RL stimuli. This progression did not appear at PO8, with the exception of the step from OC to RL.

With the aim of avoiding an unacceptable degree of loss of statistical power due to the use of the high number of electrodes [29], statistical analyses on amplitude were planned and made on a selected sample of 30 out of the total 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 three-way ANOVA was performed on the mean amplitude along the 240–296 ms window with the following repeated-measures factors: type of stimulus as a factor that could exhibit one of five levels (concrete words, abstract words, orthographically correct stimuli, random letters or controls); electrode, which included fifteen levels; and hemisphere, with two levels.

We obtained significant results for type of stimulus ($F_{4.64} = 19$; $P < 0.0001$), electrode ($F_{14.224} = 121.9$; $P < 0.0001$); hemisphere ($F_{1.16} = 31.9$; $P < 0.0001$) and the interactions type of stimulus by electrode ($F_{56.896} = 39$; $P < 0.0001$), type of stimulus by hemisphere ($F_{4.64} = 11.9$; $P < 0.0001$), and type of stimulus by electrode by hemisphere ($F_{56.896} = 5$; $P < 0.005$).

Post-hoc analyses were performed, but using only those electrodes that showed the maximum RP values across Type of stimulus at each hemisphere, that is, PO7 and its contralateral PO8, again with the aim of avoiding an unacceptable degree of loss of statistical power due to the use of a high number of redundant comparisons [29]. In this regard, pair-wise ANOVAs with type of stimulus as factor, therefore comparing each type of stimulus with one other, were carried out at each of the two electrodes separately. Corrected P values were obtained with the Bonferroni correction method. This showed that each type of stimulus was significantly different when compared with one other at PO7 ($F_{1.19} = 9.7$–178.4; $P < 0.0001$ in all cases but SCc to SCa comparisons, with $P < 0.05$). By contrast, at PO8 the comparisons between the two SC stimuli yielded no significant result; nor did the comparison of each type of SC stimuli with OC stimuli. However, all the remaining comparisons at PO8 were found to be significant ($F_{1.19} = 12.5$–79.7; $P < 0.0001$ in all cases, with the exception of SCc versus RL, SCa versus RL, and OC versus RL, all with $P < 0.05$). Thus, statistical analyses supported the existence of amplitude differences across types of stimulus at both hemispheres, though markedly at the left hemisphere.

A Profile Analysis [25] was performed. For the time window of interest (240–296 ms) in the difference waves (that is, after subtracting control stimuli from

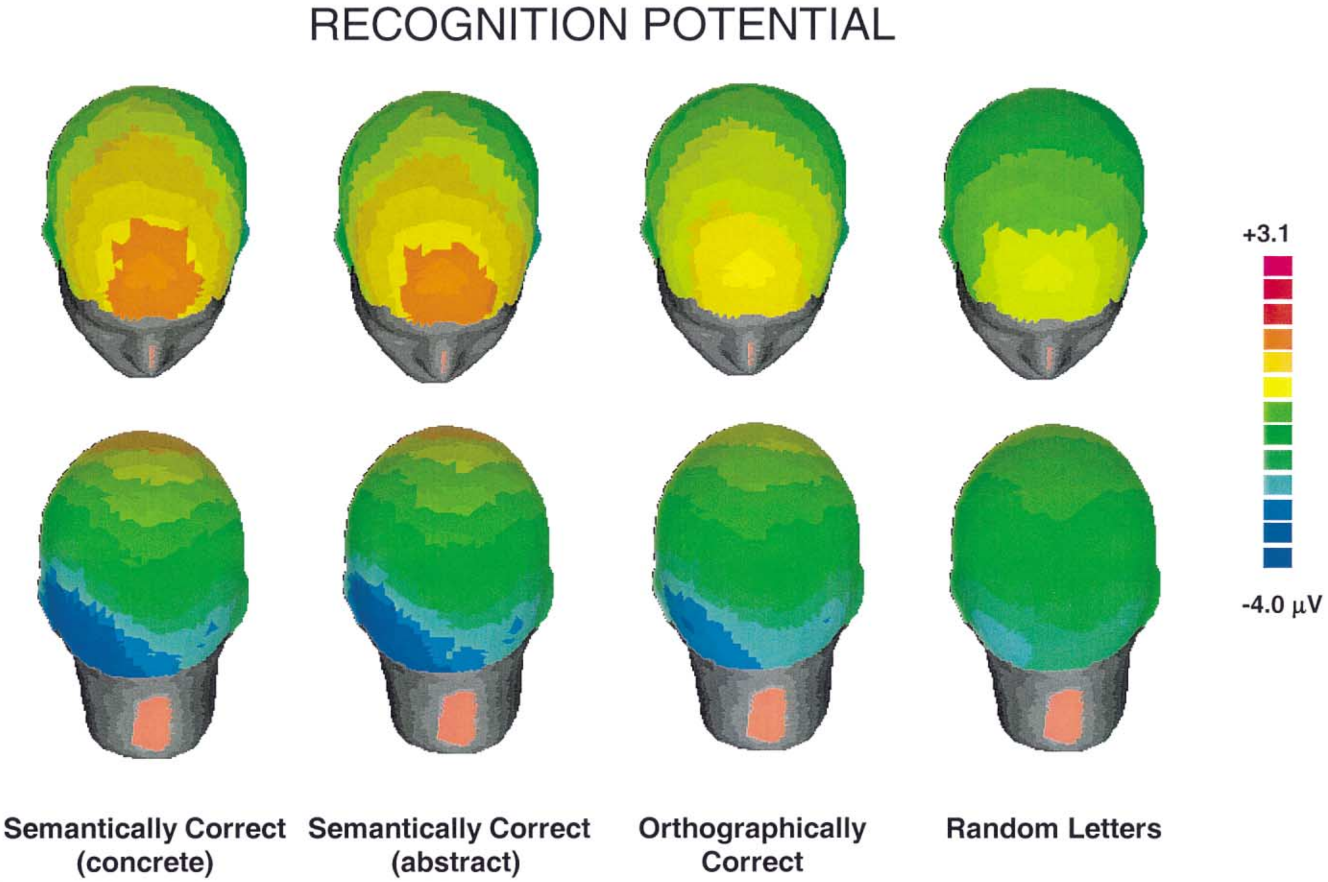

Fig. 3. Topographic maps of the RP distribution across the total array of 60 cephalic electrodes. These represent mean values for the period 240–296 ms. Again, activity to control stimuli has been subtracted from each of the waveforms to make the maps. The topography of all the maps appears notably similar, mainly consisting in an inferior parieto-occipital negativity that was slightly left-lateralised. Also, a lower-amplitude positivity over frontal and frontopolar regions can be observed. The RP amplitude decreases progressively from words to random letters.

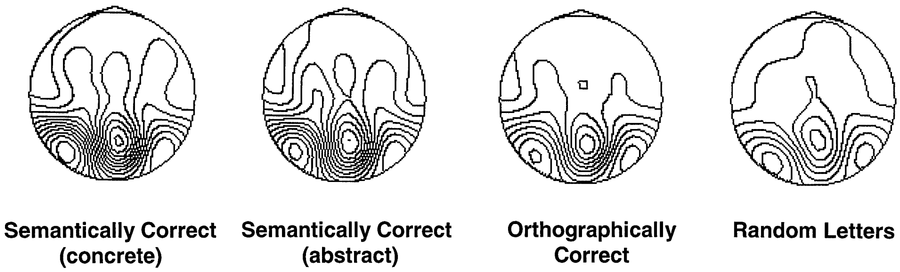

Fig. 4. Current Source Density (CSD) maps of the RP distribution across the total array of 60 cephalic electrodes for the period 240–296 ms. By means of this technique the number of sources can be better determined, as strong discrete foci in CSD maps indicate a source which most likely lies near the region of maximal density. CSD maps clearly indicate the existence of two sources, one near PO7 and the other near PO8, across type of stimulus. Each isocontour line represents a 0.05 μV/cm^2 step.

each type of stimulus), mean amplitudes were scaled for each subject across all electrodes, with the average distance from the mean, calculated from the grand mean ERPs, as denominator. Significant differences in ANOVAs with these scaled data, where possible effects of source strength are eliminated, provide unambiguous evidence for different scalp distributions [40].

An ANOVA was therefore, performed on these scaled data with type of stimulus (four levels: concrete words, abstract words, orthographically correct stimuli, and random letters) and electrode (30, because they were not actually dissociated by hemisphere) factors. This yielded no significant results in the type of stimulus by electrode interaction ($F_{87.1653} = 1.6$; $P > 0.1$). In an attempt to increase the power of profile analyses, post-hoc ANOVAs with the transformed data were also performed, but now comparing every type of stimulus with every other separately. Again, no significant differences were observed for any comparison ($F_{29.551} = 0.9$–1.7; $P > 0.1$ in all cases), with the exception of the comparison of concrete words with random letters, $F_{29.551} = 3$; $P < 0.05$. However, this significance did not hold after a Bonferroni correction. Accordingly, we could assume the same generators across types of stimulus, amplitude differences probably being attributable to differences in intensity of the activity of these generators across types of stimulus.

At this stage, therefore, the BESA algorithm was applied, assuming that all four types of stimulus presented the same topography and, hence, the same generators. On considering Fig. 3, and in close accordance with previous data [14,24], it appeared most plausible that there existed two generators at contralateral homologue areas. This was supported by the existence within each hemisphere of maxima at PO7 and PO8. Moreover, it was confirmed by current source density (CSD) maps [34], displayed in Fig. 4. By means of this technique the number of sources can be better determined, as strong discrete foci in CSD maps indicate a source that most likely lies near the region of maximal density [35]. CSD maps clearly indicated the existence of two sources, one near PO7 and the other near PO8.

Only dipole data for concrete and abstract stimuli will be displayed here, given the previously-established assumption of same generators across types of stimulus. The procedures for calculating dipoles were those detailed elsewhere [24]. Fig. 5 displays the position and orientation of the best dipole solutions for both the SCc (86.6% of explained variance) and the SCa (96.4%) stimuli. These dipole solutions largely coincided among themselves and with those found in our previous studies for words [24] and pictures [14].

4. Discussion

Regardless of the format of the semantic processes reflected by the RP, they appear to be less involved during abstract material processing than during the reading of concrete material. Actually, this is the most important finding of the present study, i.e. the lower RP amplitude for abstract nouns as compared with concrete stimuli, abstract and concrete materials being significantly distinguishable in their degree of imageability. This is a clear indication that at least one element of the semantic system is subserving some kind of perceptual-semantic or higher-level perceptual processing.

That the RP is reflecting higher-order semantic processing completely independent of input modality has been established previously [23,24]. It is clear that differences between concrete and abstract nouns used here cannot be the result of anything but semantic features. Stimuli belonging to either semantic type were identical in visual parameters (number of letters, size, luminance, etc.), both were targets, and the main difference between them could be detected only by means of a semantic analysis. RP amplitude differed between the two types of semantic stimulus, and this could only be attributable to a semantic analysis. Present data further reinforce, therefore, the previously-reported finding that RP is an ERP component sensitive to the semantic content of stimuli, that is, that RP is reflecting the activity of at least part of the semantic system. If the semantic system were a unitary one devoid of any kind of perceptual or perceptual-like format, then the RP to concrete and abstract materials should have been identical, and this was not the case. Accordingly, the present results seem to support models such as that proposed by Thompson-Schill et al. [42], whereby the semantic system would be functionally segregated into anatomically discrete modality-specific regions, that reflected by the RP activity most probably belonging to the visual modality, since the more imageable words had larger amplitudes than the less imageable stimuli.

Nevertheless, the coexistence of other semantic regions or subsystems completely free of any kind of perceptual format cannot be discarded by the present results. Moreover, the fact that abstract material also evoked a notably larger RP component than pseudowords or unpronounceable letter strings, and that the difference in RP amplitude between abstract and concrete words, though significant, was not notably large, appear to support that there is no full functional segregation of the semantic system. Rather, our data support the existence of a semantic system specialised in concrete, imageable material, but that this system is also activated by abstract material specifically selected on the basis of its low imageability. This would actually imply an intermediate solution between a unitary semantic system and a functional segregation of semantic processing.

Accordingly, these data provide an important refinement with regard to semantic processing by the human brain, to be accounted for by the models dealing with the cognitive neuroscience of semantic processing. In this line, the present results may be relatively difficult to interpret using the most frequently-preferred model to interpret concreteness effects, the 'dual-code theory' of Paivio (e.g. [32]), at least when this theory is taken literally. This model postulates two distinct representational systems. In the verbal one both concrete and abstract words are initially processed. However, the non-verbal system would only be accessed by concrete material, this access facilitating the recognition of the stimulus and, therefore, reducing RTs, this constituting the well-known 'concreteness effect' [19]. Our results seem to indicate, however, that abstract material does actually have important access to the non-verbal system, provided that this is reflected by the RP, as the amplitude of the RP for abstract nouns was notably larger when compared with that of pseudowords.

This might be interpreted in two ways, though neither of them can be fully elucidated by the present data. On the one hand, some kind of visual image might be evoked, at least to some extent, even by abstract and poorly-imageable nouns. This may indeed be the case, considering that the pool of abstract nouns used here had very low, but some degree of imageability. As stated in the methods section, the lowest possible score

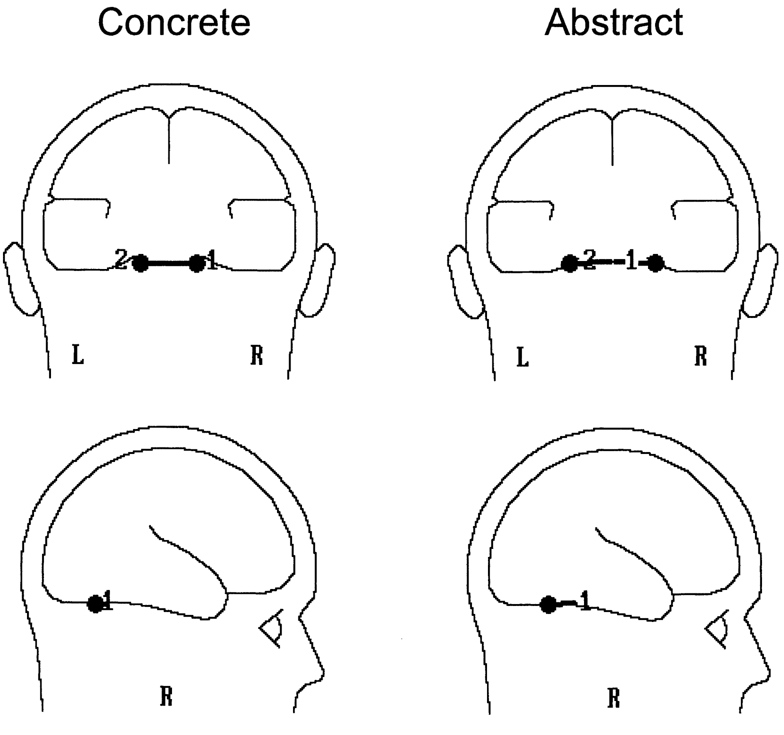

Fig. 5. Positions of the two dipoles for the RP concrete (left) and abstract (right) words. Numbers identifying each dipole are located near the sharp end of the vector representing their orientation. That is, dipole number 1 is located within the left hemisphere, and number 2 is within the right hemisphere. These positions made up the best-fit solution found for the 240 to 296 ms time range, and their location corresponds to the lingual gyri. They are based on the waves for concrete (left) and abstract (right) stimuli after subtracting the activity to control stimuli.

in the imagery dimension according to the available normalised word pool for Spanish is 1.61, and not 0, which implies that some degree of imageability should always be expected. However, this alternative would not satisfactorily explain the existence of subtle differences in RP amplitudes accompanying marked differences in imageability.

A second alternative might be that abstract material accesses the non-verbal system, but that appropriate images or visual representations for the presented word are not found. Hence, semantic identification of abstract words has to be performed elsewhere. This would actually explain the above-mentioned concreteness effects, present in our performance results, by which RT to concrete material is shorter than that to abstract material (here, 504 and 531 ms, respectively). The Recognition Potential (RP) peak latency, however, was fairly similar for either type of word, the difference between 272 ms for concrete and 268 ms for abstract material actually corresponding to a one-point distance with the 250 Hz sampling rate used here. This is an important finding, because in several studies it has been demonstrated that RP is a good predictor of RTs (e.g. [38,39]). However, in the present study the two RTs differed significantly, while peak latencies of the RP were more or less identical for abstract and concrete nouns.

This result appears to suggest that whereas the processes involved in concrete material recognition (presumably those subserved by the visual semantic processing areas or non-verbal system) may resolve at the moment the RP peaks (which would explain previously-reported RP correlation with RT, concrete material being that most frequently used in RP studies), other, subsequent processes would be involved in order to clearly recognise abstract nouns. Hence, abstract material would access some other kind of semantic system after accessing this visual semantic system. Subsequent access to this system would be on the basis of the RT increase found for the abstract material.

The present data, obtained with 60 cephalic EEG channels and dipole analyses, results in notable advances relative to previous ERP and haemodynamic research on abstract versus concrete words comparisons. In fact, they might explain why previous neuroimaging studies have conflicted as regards the involvement of basal extrastriate areas in the processing of abstract and concrete materials [4,16]. Haemodynamic techniques actually use a pure subtractive approach whereby paired *t*-tests or ANOVAs are used instead of direct subtractions [5]. As a consequence of these procedures, data are often described in terms of absolute activations (or deactivations) based on statistical significances, and this is usually relative to a baseline or basal condition. As our data reveal, abstract words with poor imageability activate visual semantic areas considerably, though to a slightly lower extent than concrete imageable words. Accordingly, activations of these areas by abstract material may or may not incidentally cross the threshold for statistical significance, as they would be in some intermediate position relative to activations by concrete material. The specific degree of activation of semantic processing areas within the basal extrastriate regions by abstract words would depend on several factors, among which may stand out their actual degree of imageability.

Previous studies on electrical signals of the brain found different topographies for abstract and concrete materials. Specifically, the studies by Holcomb et al. [15], Kounios and Holcomb [18], West and Holcomb [44], and Koenig et al. [17] have reported as the most common finding either a more frontal distribution for abstract material or a right-sided distribution for concrete material. These data contradict somewhat those obtained with haemodynamic techniques, which not only failed to report an anterior-posterior distinction, but also reported the right hemisphere as playing a relatively greater role in processing abstract words. It appears, therefore, that there is a heterogeneous group of findings regarding lateralities and topographic differences between concrete and abstract words processing. Whatever the specific differences, and according to our data, we might propose that these different distributions could be attributed to processes occurring after access to the visual semantic system by both types of material. Our data seem to indicate that at this stage the two materials do not differ in terms of topography. However, after this step the processing of the two types of words would differ, and this may be reflected by different topographies. This would be supported by the fact that the main differences between concrete and abstract materials in the cited studies on electrical signals of the brain were found to start at about 300 ms, or were found for the N400 component, both of these phenomena having longer latencies than the RP studied here. Unfortunately, the procedures for obtaining the RP do not permit us to study other subsequent components or their topography, as they involve baseline subtractions in order to eliminate driving signals produced by the rapid stream stimulation, which would in turn mask other ERP components [37]. In Fig. 2 it can be seen that no other ERP component is present before the RP. After the resolution of the RP we can see a polarity inversion of all the RP effects, these displaying the same topography as the RP, but peaking at about 470 ms. These long-latency RP-like effects have been reported previously [24], but cannot be properly explained at the moment.

In line with the comments outlined in the previous paragraph, it appears interesting to discuss briefly here why the differences between concrete and abstract words in RP amplitude were found only for the left hemisphere. Previous findings on RP indicate that the semantic information processing reflected by this component is taking place mainly within those basal extrastriate regions of the hemisphere where the main perceptual analyses of the incoming stimuli are being performed [14]. Different access routes to these basal extrastriate areas would be used depending on whether the input stimuli are pictures or words [26], the activation of the left side being larger when they are words, as words seem to imply a route passing through certain strongly left-lateralised areas, such as Wernicke. Accordingly, given that in the present experiment all the stimuli were words, we should expect the left hemisphere to be the main place where the analyses reflected by the RP occur. This would explain the overall left-lateralised RP amplitude and why the differences between concrete and abstract words mainly occur within this hemisphere.

Finally, it can be mentioned that a major drawback of present study might be the lack of an absolute control of the imageability dimension. Certainly, in order to effect such a control we would further need concrete non-imageable words and abstract imageable words. This is the case in a previous study for English [44], but seems impossible in Spanish according to the normalised databases available [1,2], since no concrete non-imageable words would appear to be available. This objection, however, does not pose any problem for our main conclusions, that is, that at least part of the semantic processing system specialises in visual-semantic processing, and that this part of the semantic system is accessed by both concrete and abstract words, even when important efforts are made to reduce as much as possible the degree of imageability of abstract material.

Acknowledgements

The authors wish to thank Pilar Casado, Nuria Lauzurica, and Francisco Muñoz for their help in data collection and analyses. We also thank Professor Salvador Algarabel for highly valuable comments and help with the preparation of this manuscript. J.A.H. is granted by the Dirección General de Investigación, Comunidad Autónoma de Madrid. This study was supported by grants of the D. G. Investigación, Comunidad Autónoma de Madrid, 08.5/0037.1/99, and Fondo de Investigaciones Sanitarias, 00/0515.

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