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Review

The gate for reading: Reflections on the recognition potential

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ABSTRACT

The recognition potential (RP) is an electrical response of the brain peaking around 200 to 250 ms after stimulus onset and obtained when subjects view recognizable images, such as words or pictures. There is considerable debate as to whether the RP reflects a visual–structural step in the perceptual analysis or a part of the semantic–conceptual processing of the stimulus. The functional response of the RP noticeably resembles that of the seemingly controversial visual word form area (VWFA). This parallelism is hereby developed, and proposals for a processing system presumably accounting for the heterogeneous results on the RP are also suggested. According to these proposals, the RP is originated in the VWFA, an area that would play a cardinal role in the reading process, receiving and integrating different types of information that extend from letter identification to contextual semantic information.

Contents

1. Introduction. The recognition potential and the procedures to view it

The recognition potential (RP) is an electrical brain response peaking around 200 to 250 ms, obtained when subjects view recognizable images, such as words (Martín-Loeches et al., 1999; Rudell, 1991; Rudell and Hua, 1997) or pictures (Hinojosa et al., 2000; Rudell, 1992). Since the very first report on this component by Alan P. Rudell in 1990 (Rudell, 1990), a noticeable amount of studies have appeared with the RP as the main focus of interest, contributing in determining the cognitive processes related to this component. Even so, the resolution of this issue

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still appears elusive. It is the purpose of the present paper to review evidence on the current functional interpretations of the RP, suggesting an account of this component that attempts to harmonize the apparently contradictory views in this regard.

The RP is usually obtained by a procedure called rapid stream stimulation (RSS). This procedure, developed by Rudell (1992) (see also Hinojosa et al., 2001b), is to some extent similar to the rapid serial visual presentation (RSVP) paradigm frequently used in psycholinguistic research, but in which recognizable (words or pictures) and non-recognizable (background) stimuli alternate at a high rate of presentation (usually with a stimulus onset asynchrony – SOA – of 250 ms). Background stimuli are devoid of both structure and meaning but display identical physical attributes to those of the recognizable stimuli. Mostly, background stimuli are presented to subjects, and periodically (after at least two to either six or seven background stimuli, this number randomized) a test stimulus is presented.

The reasons that brought about the development of the RSS were several. The rapid rate of image presentation was introduced with the intention of forcing subjects to process the stimuli at regular short time intervals, decreasing the variability between and within subjects when they perform the reading test. The presence of background stimuli was originally introduced in order to avoid or reduce visual-related components such as the N1-P2 complex, as their latency largely overlaps with the RP. The background stimuli would act to preempt stimuli by temporally usurping activity in the visual afferent pathway. Accordingly, a second image presented immediately or a very short time later appears in the aftermath of activity evoked by the preempt stimulus, which by leaving some elements of the brain in a refractory state prevents the second image from fully developing its normal electrophysiological response (Rudell, 1991). In addition, background stimuli are always presented between recognizable stimuli; that is, two words or pictures are never presented consecutively, presumably because the RP to the second recognizable stimulus would be overlapped and contaminated by components evoked by the previous stimulus.

Finally, the number of backgrounds between recognizable stimuli cannot be fixed to either one or two, since the appearance of a recognizable stimulus has to be unpredictable to subjects. Otherwise, the subjects could displace their attention during the appearance of background stimuli, reallocating attention only when target stimuli are going to appear. Then, implementing a rapid rate of presentation would be useless. In Iglesias et al. (2004) it was demonstrated that the minimum number of backgrounds between recognizable stimuli is two, since interspersing a single background seems to introduce a contamination of the waveforms by the presence of a slow negativity in response to the preceding recognizable stimulus overlapping the RP time window.

In Iglesias et al. (2004) it was also shown, nevertheless, that the RSS is not mandatory to attain the RP. Rather, the RSS is merely a procedure to enhance the signal-to-noise ratio and, hence, the visibility of this component without adding strange or undesired variables not present when using more standard paradigms, as the RSVP. According to that study, the probability of appearance of a recognizable stimulus relative to backgrounds has virtually no effect, the presentation of background preceding a word merely avoiding the overlapping of ERP fluctuations to previous word stimuli. When no background is used the RP can still be obtained, though the component appears unclean, somewhat distorted, and with an uncertain peak. On the other hand, when in absence of backgrounds the SOA is increased from the usual 250 ms to 500 or 1000 ms, as an alternative to diminish the overlapping of fluctuations evoked by previous recognizable stimuli, the RP not only becomes contaminated by the presence of concurrent visual-related components, but also by a noticeable increase of the P200 at fronto-central leads. This P200 increase significantly affects the average reference desirable for a component that is maximal at a position (PO7 electrode, that is, left inferior parieto-occipital junction) not far from the mastoids.

Rudell's first works are also good demonstrations that the RP can be obtained without using the RSS (Rudell, 1990, 1991). In Rudell (1991), particularly, dozens of different stimulus configurations were compared. In most of them recognizable stimuli surrounded in the same display by control or unrecognizable stimuli were presented, and presentation rates could be as long as 1 to 4 s. A visible RP was obtained whenever the electrical activity of images containing a recognizable stimulus was contrasted to images containing only control stimuli. Somewhat as an anticipation of the RSS, nevertheless, in that study Rudell always used 'preempt' stimuli, i.e., non-meaningful images similar to control images and flashed a short time (e.g., 83 ms) before each to-be-analyzed image (either control or containing a recognizable stimulus within).

But indeed the RP can also be obtained by several alternative methods. Dien et al. (2003) published a study in which the RP was obtained by means of a temporal principal component analysis (tPCA). Dien and colleagues used a stimulation paradigm where only recognizable words were presented, constituting readable sentences in which the last word could be congruent or not relative to the preceding sentence context. The word-by-word presentation rate was 1005 ms, and each word was displayed for 105 ms. With such a rate of presentation, and in the absence of preempt or background stimuli, tPCA on a large sample of subjects appeared to be a requisite to attain visible RPs. Indeed, this technique has been recommended for the detection and quantification of components if the use of the traditional visual inspection of grand averages may lead to misinterpretations (e.g., Chapman and McCrary, 1995). By using a sum-of-squares-cross-products matrix of the voltage readings at each time point, at each of the electrode positions, and for each of the words studied, Dien et al. (2003) obtained a simple structure after a Promax rotation. Thereafter, the factors scores were rescaled to microvolts by multiplying the scores by the factor loading and the standard deviation of the peak time point. As a final result, single dissociable components could be isolated and effects studied on them. With this procedure, Dien and colleagues could report a RP to words, being differentially sensitive to the variables expectancy and meaningfulness in sentence contexts.

Last, but not least, the study by Marí-Beffa et al. (2005) represents evidence that by looking carefully at the appropriate electrodes and time intervals, RP-like deflections can be observed even with traditional visual inspection of grand averages obtained with procedures as dissimilar from the RSS as a prime task in which the prime and the probe stimuli are presented in isolation, with no preempt or background stimuli in between and long SOAs.

There are two main functional interpretations of the RP. One proposal is that this component reflects visual image recognition. Then, the main variables to be studied concerning the RP would pertain to visual physical parameters, such as size, form, visual distinctiveness, location, and so on. An alternative proposal has stressed the idea that the RP is sensitive to semantic or conceptual processing. The RP would constitute, according to the later view, an excellent tool in approaching the organization of the semantic system in the brain. In spite of apparent incompatibility, however, each functional point of view has given place to an independent line of research and evidence, each contributing to further reinforce and refine each corresponding interpretation. In the following, both points of view are reviewed.

2. The RP as an index of visual processing

In the very first study on the RP (Rudell, 1990), a summary of main unpublished findings by Rudell remarked on the sensitivity of this component to recognizable images, such as words, cartoon faces, simple pictures, and geometric patterns. Subsequent studies by this author and colleagues mainly focused on further describing the visual or 'gestaltic' features that affect this component.

It was thereafter stated that the RP is a peak at about 200–250 ms (Rudell, 1992), but that several experimental manipulations may increase the latency of the component, such as degrading the quality of the image (Rudell, 1991; Rudell and Hua, 1995), superimposing random dots patterns (Rudell and Hua, 1997), applying a preempt stimulus (Rudell and Hua, 1995), or comparing difficult words versus easy words (Rudell, 1999; Rudell and Hua, 1997). On the other hand, other factors such as word-priming or the presence of a preceding warning signal may decrease its latency (Rudell and Hua, 1996a, 2001). Furthermore, RP amplitude and latency are unaffected by the performance of motor responses (Rudell, 1991). Even though, reaction time (RT) is strongly correlated to the latency of the RP, and it has been shown that this latency is about 150 ms shorter than RT (Rudell and Hua, 1997).

Since the RP is so closely related to both recognition processes and RT, it was directly contrasted with the P300 (Rudell, 1990, 1991, 1992; Rudell and Hua, 1997). It was found that, unlike the P300, the RP does not depend on an element of surprise (Rudell et al., 1993). Additionally, the RP is a better RT predictor than the P300 (Rudell, 1992; Rudell and Hua, 1997). Further, and again contrasting with the P300, the RP is sensitive to the visual area stimulated, as the polarity of the RP varies as a function of the position of the stimulus within the visual field (Rudell and Hua, 1995; Rudell et al., 1993).

It soon became evident that the RP is strongly related to conscious awareness of stimuli, selective attention being an important factor for evoking it. This was illustrated in the Rudell and Hua (1996b) study, in which subjects were familiar with both Chinese and English languages. Chinese and English words could appear as stimuli, and subjects were told to attend to just one language. Interestingly, the RP appeared only to the attended stimuli. Also of interest was the finding of the RP as a predictor of reading ability. Rudell and Hua (1997) found that subjects obtaining the highest Graduate Record Examination Verbal scores showed shorter latency RPs. The authors inferred from these results that the RP may be reflecting the perception speed of words due to a specific language skill, proving the feasibility of using this component for studying individual differences in visual word perception.

Most of the pioneering research on the RP by Rudell and colleagues focused on word recognition. Indeed, up to 1999 the only published exception was the Rudell (1992) study in which pictures were also used as recognizable stimuli. As a consequence, the idea that the RP might be a valuable tool in the study of visual language perception started to crystallize. In 1997, Rudell and Hua proposed the possibility of the RP actually being sensitive to semantic processing of the images. Indeed, if that were the case, the relevance of the RP would be considerable, since the most standard ERP component used to study semantic processing, the N400 (Kutas, 1997), usually peaks at about 400 ms, a rather late latency considering that semantic processing may be accomplished as soon as by 250 ms during reading (e.g., Sereno et al., 1998). Moreover, whereas the N400 requires a violation of the semantic context to be perceived, the RP could suitably be obtained to correct material. Consequently, the RP appeared as a better candidate to approach semantic processes. This was actually the line of reasoning that gave rise to the development of the alternative functional interpretation of the RP.

But the main account of Rudell and colleagues about the RP still focused on visual processing. As a result, two subsequent studies by this group did not use words as stimuli, but single letters. In Rudell and Hu (1999), an RP to single letters was shown, which was affected by the degree of visual complexity of the area surrounding the target letter. In a similar paradigm, it was demonstrated that the identification of reversed letters delays the peak of the RP, relative to non-reversed materials (Rudell et al., 2000). Accordingly, stimuli completely devoid of semantic content were able to evoke a RP, thus suggesting that the RP is an indication of the moment at which the Gestalt pattern of a visual stimulus is identified rather than of any semantic processing (Rudell et al., 2000).

Very recently, Pu et al. (2005) have reported evidence favoring this functional interpretation of the RP. Keeping recognizable words constant, the amplitude of the RP was found to notably vary as a function of the perceptual similarity between the background and the target stimuli. Then, the RP to real words was larger when the backgrounds were composed by word fragments, as in the standard RSS paradigm, the amplitude progressively decreasing when the backgrounds were unpronounceable non-words or pseudowords.

3. The RP as an indicator of semantic processing

Following the Rudell and Hua (1997) proposal of the RP as possibly sensitive to semantic processing, Martín-Loeches and colleagues considered this an interesting idea to be further developed. In their study, Rudell and Hua (1997) could not rule out that the RP could be related to orthographic analysis instead of semantic or conceptual processing, since they only compared real words with unpronounceable letter strings. An intermediate, orthographic, level was missing, and this had been the case for all the previous studies on the RP (Rudell, 1990, 1991, 1992; Rudell and Hua, 1995, 1996a,b, 1997; Rudell et al., 1993).

Martín-Loeches et al. (1999) incorporated the missing intermediate level by presenting pronounceable non-words in addition to real words and unpronounceable letter strings, finding that the RP displayed noticeably the highest amplitude values for real words. This was taken as direct evidence of the sensitivity of the RP to semantic aspects of the stimuli. An alternative explanation for those initial data, however, could have been that real words displayed the highest RP values simply because they were recognizable, that is, previously known by the visual system of the subjects. Even so, Martín-Loeches and colleagues initiated a line of research in which the RP was considered an important sign of semantic processing, soon finding unambiguous evidence for this functional interpretation of the RP.

In this regard, the RP amplitude was found to consistently differ in accordance with word features that could only be achieved by means of appropriate semantic processing. Hence, the RP amplitude differed as a function of the semantic category of the stimuli. In Martín-Loeches et al. (2001b) animals versus non-animals were compared and the former displayed higher RP amplitude values than the latter, keeping constant not only the visual or perceptual features of the words of either category, but also other lexically relevant factors such as word frequency or word length. The RP amplitude was also larger for concrete than for abstract words (Martín-Loeches et al., 2001a), and for open as compared to closed-class words (Hinojosa et al., 2001a). The sensitivity of the RP to the semantic abstract–concrete dimension has been replicated recently in a different group of subjects, and it has been also found for schizophrenic patients (Martín-Loeches et al., 2004b). In this recent work, moreover, patients with though disorder, presumably caused by problems in their semantic system, displayed particularly reduced RP amplitude, reinforcing to some extent the semantic interpretation of the RP. Also recently, it has been found that the RP is affected by the semantic plausibility of the word within a given sentence context, in parallel with the N400 (Martín-Loeches et al., 2004a).

Further evidences favoring the semantic interpretation of the RP came from the studies by Dien et al. (2003) and Marí-Beffa et al. (2005). Dien et al. (2003) found that the functional response of the RP might vary from one hemisphere to the other. In this regard, the RP originated in the left hemisphere appeared to be sensitive to the degree of fitness of the semantic content of a word with the preceding sentence (expectancy context). The RP originated in the right hemisphere, however, appeared sensitive to the meaningless dimension regardless of the expectancy dimension. On the other hand, Marí-Beffa et al. (2005) reported that a fluctuation with latency and topography resembling those of the RP was found to be sensitive to the semantic category (namely, living versus non-living) of prime words in a priming experiment.

Finally, it has been determined that the neural generators of the RP may be located within basal extrastriate areas, particularly within the lingual and/or fusiform gyri, and bilaterally though mainly in the left side (Martín-Loeches et al., 2001b; this result has been consistently replicated in subsequent studies). Given this location, and the differences in the RP amplitude as a function of certain semantic categories (concrete versus abstract or animals versus non-animals), it has been suggested that this component might be reflecting the activity of a part of the semantic system, namely of that part concerning visual–semantic knowledge (Martín-Loeches et al., 2001b), in consonance with recent proposals of distributed semantic networks across the cortex (Pulvermüller, 2001).

4. Trying to see the wood for the trees: the RP and the visual word form area

In their recent work, Pu et al. (2005) stressed the problem of the functional interpretation of the RP. Indeed, the title of that study accurately illustrates the current dichotomy in this regard: the recognition potential: semantic processing or the detection of differences between stimuli? In our view, the functional interpretation of the RP may be problematic if we adopt a strictly dichotomist mode of thinking. If it is thought that the RP can reflect either gestalt visual processing or semantic processing, but not both, we do have a problem.

Dien et al. (2003) suggested that the RP might be originated in the visual word form area (VWFA). Indeed, the functional parallelisms between the so-called VWFA and the RP are outstanding and cannot be ignored. On the one hand, the VWFA appears located within the mid-fusiform gyrus, mainly left (Price, 2000), this being the region proposed as the origin of the RP (Martín-Loeches et al., 2001b; Dien et al., 2003). On the other, the VWFA has been shown to be sensitive to a constellation of factors, among which semantic and word form analyses are conspicuous. Even though, it has been seen also affected, at least to some degree, by other types of variables such as phonological features or motor responses (for recent reviews, see Price and Devlin, 2003, or Démonet et al., 2005). To which extent the RP may be affected by these other variables still needs to be explored, although Rudell (1991) reported that the RP is not apparently affected by motor responses. Even though, other outstanding similarities between the functional response of the RP and the VWFA can still be mentioned, such as a differential activation for different degrees of information contained in the stimuli, that is, as a function of the increasing 'wordness' of the stimuli from consonant strings, to pseudowords, and then to words (see, e.g., Cohen et al., 2000, for the VWFA; Martín-Loeches et al., 1999, for the RP).

Finally, the activation of the so-called VWFA has been seen to start at about 200 ms after stimulus onset (Nobre et al., 1994), as is the case for the RP. In this line, a negativity associated to the VWFA in the frame of an ERP-fMRI study displayed both latency and topography highly similar to those of the RP (Dehaene et al., 2001). Interestingly, the negativity reported by Dehaene et al. (2001) was insensitive to case, while the RP has been seen to be unaffected by whether task requires attending to case or to semantic content (Hinojosa et al., 2004).

Assuming that the origin of the RP is in the VWFA appears therefore plausible and parsimonious. Taking this as a starting point, we can develop a proposal of the functional processes reflected by the RP integrating previous findings on this component and presumably accounting for its apparently incompatible functional interpretations.

In Fig. 1 the models have been represented by Bruce and Young (1986) for face processing, Ellis and Young (1996) for object processing, and Black and Behrmann (1994) and Valentine et al. (1995) for the visual processing of names, which can also be applied to words in general. Indeed, the RP has been obtained for all of these types of stimuli. These models propose that the initial analysis stages of faces, objects, or names include pictorial and structural (word form in the case of names) encoding, providing the necessary information for the succeeding so-called face recognition units (FRUs), object recognition units (ORUs), or name recognition units (NRU), respectively. In the corresponding recognition units, the products of structural encoding are matched with stored structural representations of known faces, objects or names, respectively, from where semantic information can be activated. Although other models may also be available in the literature, those depicted in Fig. 1 have the double advantage of being widely accepted and comprising most of the stages and components that have been suggested in other proposals.

The models depicted in Fig. 1, together with the data from the Martín-Loeches et al. (2005) study, may help us to better understand what do we see when we look at the RP. In Martín-Loeches et al. (2005), ERPs to names of persons, names of objects, faces, and pictures of objects were compared. It was concluded that whereas the recognition units appear reflected by the activity of a fluctuation peaking shortly after the RP and called early repetition effect (ERE) or N250r, the RP would rather be reflecting structural or word form analysis stages. Indeed, the RP to faces peaked much earlier and more conspicuously than to the remaining stimuli (while displaying the same topography), being therefore considered a parallel of the N170 traditionally considered as reflecting structural analysis of faces (Bentin et al., 1996), but of shorter latency due to presumable specialized systems for face recognition. By looking at Fig. 1 it becomes evident that there is a parallelism between the stage for structural analysis of faces and objects, and for word form analysis of words or names.

Accordingly, if the processes reflected by the RP cannot be mainly assigned to the recognition units stage, which appears to occur later, other subsequent stages as the semantic one should also be discarded. On the other hand, stages preceding the word form or structural analysis should also be disregarded as mainly related to the RP, since they are better reflected be earlier components, as the P100 related to primary visual processing and sensitive to features such as contrast, brightness or size (Schendan et al., 1998). The proposal by Dien et al. (2003) that the RP reflects word form analysis appears consistent.

However, as has been repeatedly mentioned here, the RP is sensitive to semantic aspects of the stimuli. And this is not all. Actually, the RP is differentially sensitive to information pertaining to each one of the different stages proposed by the models depicted in Fig. 1. In this regard, Fig. 2 outlines the relative amplitude of the RP as a function of the deepest stage that a given stimulus can reach. Next to the schematic waveform, the different stages proposed in the models in Fig. 1 are represented, with an idealized percentage of the contribution of each stage to the total amplitude of the RP, based on empirical data (namely, from Martín-Loeches et al., 2001a; Hinojosa et al., 2001c). As can be seen, unpronounceable non-words containing sets of random letters can also yield a small but visible RP, calling for the inclusion of an additional stage in the models of Fig. 1, a stage for letter identification located between visual and word form analyses. This is in line with several other proposals for word recognition (e.g., Caplan, 1996).

As a result, I propose the diagrams in Fig. 3 as an aid to better understand the possible processes reflected by the RP. There,

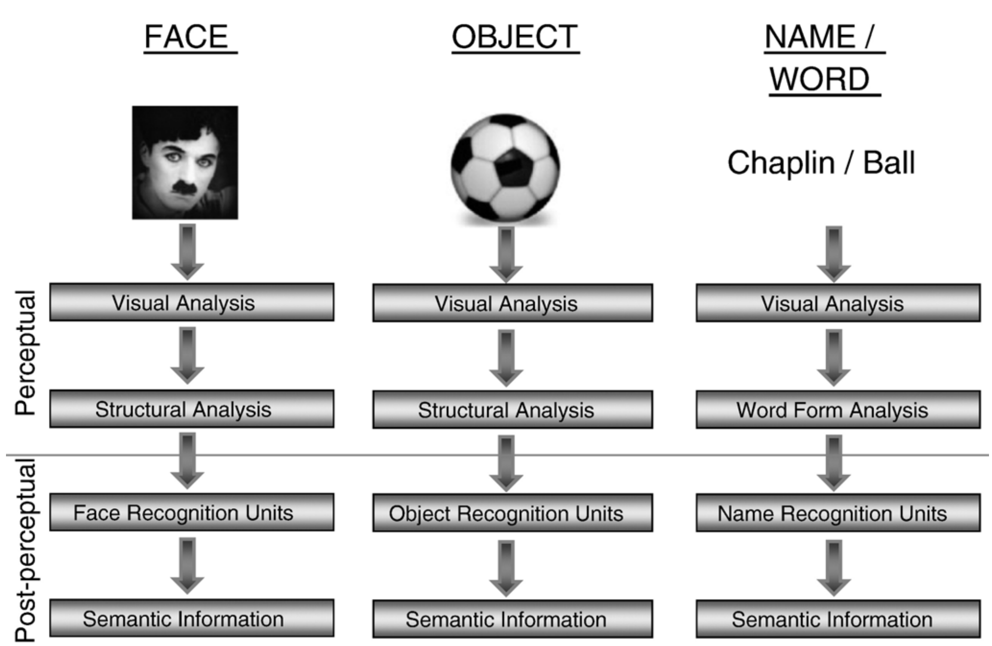

Fig. 1 – Schematic view of the models by Bruce and Young (1986) for face processing (left), Ellis and Young (1996) for object processing (center), and Black and Behrmann (1994) and Valentine et al. (1995) for the visual processing of names (right).

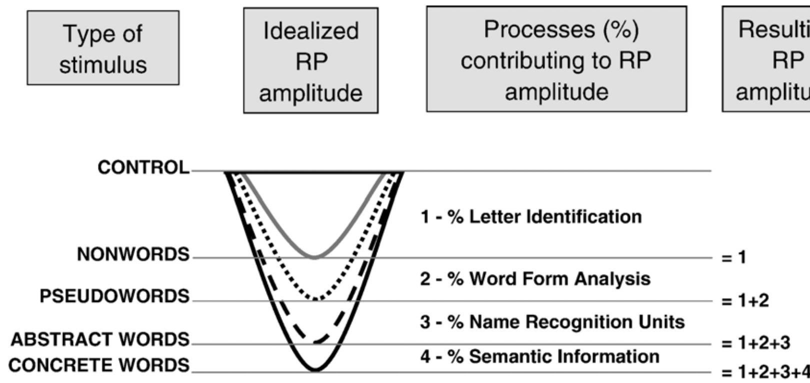

Fig. 2 – Idealized relative amplitude of the RP as a function of the deepest process a stimulus can reach.

word processing is on the scope, but the diagrams could apply to other types of stimulus as well. Fig. 3A is merely the result of entailing two main addenda to the models in Fig. 1, required to account for most RP results: a letter identification stage, and a number of arrows signaling back—in addition to forward direction of information processing. Feedback circuits appear needed in order to understand why semantic information may affect a perceptual stage (word form analysis), this suggestion being in accordance with well-known assumptions on 'top-down' effects in the perceptual system (e.g., Mechelli et al., 2004).

But top-down effects on word form analysis should not be limited to the semantic factors. Indeed, the recognition units stage should also exert some type of top-down influence. In my opinion, this is reflected in most (if not all) of the difference in amplitude between abstract words and pseudowords, as prototype of the semantic features affecting the RP amplitude. Whereas abstract words should activate recognition units, as templates for these known words must exist, their activation of that part of the semantic system presumably reflected by the RP, that is, visual–semantics, should be weak or negligible. On the other hand, bottom-up effects from either the visual analysis stage or the letter identification stage on word form analysis should also be admitted. Whereas the experiments by Rudell and Hu (1999) or Pu et al. (2005) support an influence of basic perceptual factors on the RP, the amplitude difference between unpronounceable strings of random letters and pseudowords would mainly reflect the bottom-up influences of the letter identification processes on the word form stage reflected by the RP.

An alternative proposal is depicted in Fig. 3B, which should be seen as complementary to the proposal in Fig. 3A, or as a further step in the development of that proposal. At variance with a more serial-like proposal as the one in Fig. 3A (although a strict seriality is not a necessary assumption for that proposal), the scheme in Fig. 3B suggests that the VWFA might be accessed directly and in parallel or in cascade by the rest of the stages involved in reading. Several recent proposals admit parallel or in cascade interactions between the stages involved in word reading (e.g., Hauk et al., 2006). Even though, the

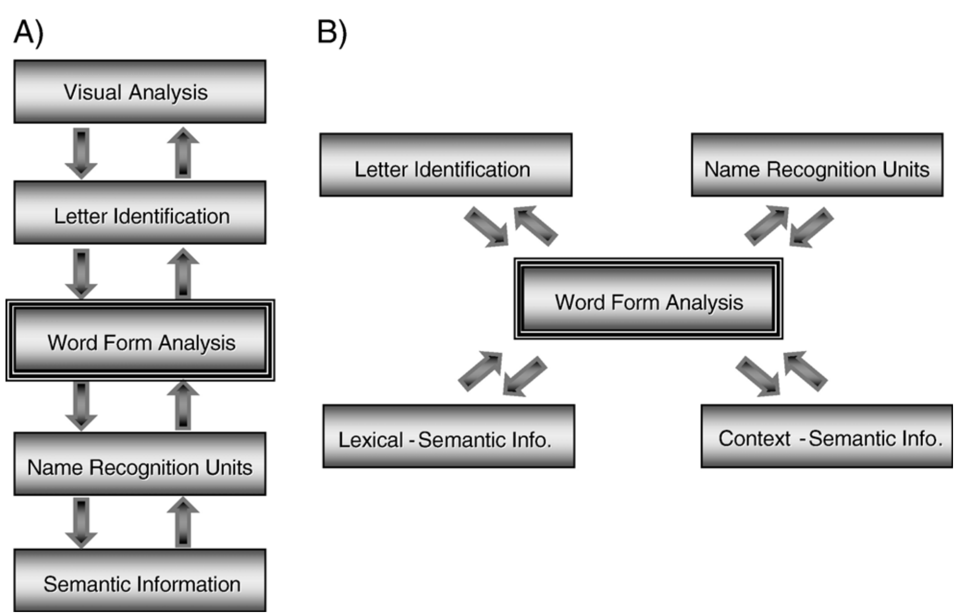

Fig. 3 – Proposals for word processing that might explain the RP. Both assume that the RP is originated by the word form analysis stage. (A) A direct derivation of the models in Fig. 1. (B) The proposal in panel A modified to a more parallel approach.

proposal in Fig. 3B just focuses on the mutual relationships between the VWFA and the rest of the involved stages, and no assumption is made on the other interactions.

In my view, this second possibility appears more directly supported by empirical evidence on the RP, and might solve, at least to some extent, several problems that could emerge if the proposal in Fig. 3A is considered in a strictly serial manner. The first problem that would be solved is not, in my opinion, a secondary one. The letter identification stage could not be achieved if a number of local substages are not assumed. That is, in order to identify letters one would need to assume that letter forms are detected and thereafter contrasted with presumably existing letter recognition units, in parallel with the processes assumed for word identification. The existence of these subprocesses might appear to complicate a more serial-like proposal as the one in Fig. 3A, whereas in the proposal of Fig. 3B they could be more easily accepted and integrated (see the last section, nevertheless, for more comments on letter identification).

A second question is the presence of an additional semantic process affecting word form analysis. As mentioned, context-relevant semantic information affects RP amplitude (Martín-Loeches et al., 2004a; Dien et al., 2003). Nonetheless, this problem can be easily resolved in the proposal of Fig. 3A by simply splitting the semantic information stage into two.

The proposal in Fig. 3B also overrides any possible influence of visual pictorial analyses on the RP. The studies by Rudell and Hu (1999) and Rudell et al. (2000) did not treat directly with these very early features, rather reporting the influence of a subsequent stage, letter identification, on the RP. The study by Pu et al. (2005) mainly manipulated this same stage and the word form stage to see their influence on the RP. Then, according to the available literature, pictorial effects on the RP are either negligible or still pendant of research. Nevertheless, it could be reminded here that the RP has been sensitive to the area of the visual field stimulated (Rudell et al., 1993). Although this feature does not pertain to the pictorial domain, the implication of this finding for the proposals here outlined should remain open.

A further problem better solved by the proposal in Fig. 3B is the occurrence of one and the same latency for the RP regardless of the specific stage that has yielded the fluctuation. In a parallel or cascade manner, the VWFA would receive and integrate the results, or at least the partial results (semantic analyses might start as soon as 80 ms after stimulus onset; e.g., Skrandies, 1998), of the remaining processing stages, in order to yield a unitary response conspicuous in time (around 200–250 ms, the RP). This response could in turn be relevant information sent back to the other processing stages to fulfill their analyses. The strength (i.e., the amplitude) of this response would be a direct function of the number of stages contributing to this process.

This proposal, albeit speculative, appears plausible in view of the behavior of the RP. Indeed, the VWFA has been proposed as a highly multimodal region that harbors distinct subcomponents of different functional networks and participates in different cognitive functions (Price and Devlin, 2003), which is in consonance with the proposal of a central role for the VWFA, as developed here. In this regard, the VWFA and, consequently, the activity reflected by the RP, can be viewed as central for the reading process and, then, could be considered as the gate for reading.

5. Open questions

Some open questions could still remain, nevertheless, after accepting either of the two proposals in Fig. 3. One is that the identification of the VWFA as the origin of the RP is just an assumption, even if highly plausible. Further research could still be needed to make this assumption plainly valid. A second question, already mentioned, is the integration of pictorial and visuospatial variables into the proposals developed here, a question still pendant of further research. A third question would be that the possibility of the RP as directly reflecting the activity of visual–semantic areas could not totally be disregarded. Top-down effects could merely explain why a given stimulus devoid of meaning, such as random letters or pseudowords, could activate to some degree the regions devoted to these processes, as a preparatory initial activation in view of possibly incoming meaningful stimuli. This has been the interpretation of the present author in former times (e.g., Martín-Loeches et al., 2001b). But it currently appears to me as less plausible for several reasons.

One is the already mentioned precedence in time of the RP when compared to other components more directly reflecting the recognition units processing stage (Martín-Loeches et al., 2005), a stage in turn presumably preceding semantic processes (at least form a serial point of view as that developed in Fig. 3A). Furthermore, considering that the RP has been seen to be also sensitive to context or sentence semantics (Martín-Loeches et al., 2004a), one could then propose that the RP might be directly reflecting the activity of semantic context or meaning integration areas. This would be, in my opinion, a highly implausible idea, which suggests that the position of the process directly originating the RP does not necessarily relate to the highest level to which it is sensitive. Last, but not least, the experiments by Rudell and Hu (1999) on letter identification demonstrate that semantic features are not necessary neither as a variable present in any of the stimuli of the experimental session nor as task requirements.

In line with the abovementioned experiment by Rudell and Hu (1999), it could be also argued as a fourth open question that the RP could in fact be originated in regions specialized for letter identification rather than for word form. Indeed, we afford here with a certainly controversial issue. Up to date, most models do not propose specialized brain regions for letter identification as different from word form (e.g., McCandliss et al., 2003). In this regard, Dehaene (2005) has very recently argued that the VWFA could have been a region specialized for detecting complex visual patterns, a region that would have been shaped by evolution for different purposes than reading, but that has been recently incorporated into the reading process to detect word forms. Dehaene (2005) suggests that they have been the writing systems who have evolved constrained by our visual system, not the opposite. Strikingly, however, when Dehaene provides examples on the types of visual patterns to which the VWFA would be specialized for, these result to be, rather, letter instead of word form patterns. For instance, Dehaene appropriately suggests that the system is specialized for detecting circles, and this would yield the letter "o" or, by combining two of these circles, the number "8". The same would apply for the detection of bars, which could have aided in the creation of the letter "T" as the result of crossing two bars. As can be seen from these examples, either we change the name of the VWFA by VLFA (L for "letter"), or we do assume that letters and word forms are detected in the same regions.

However, recent findings suggest that letters and words may indeed be identified by different, even if adjacent, neural networks (James et al., 2005). In my view, differences in amplitude in the RP between strings of letters and pseudo-words also appear to support this extreme, these differences being the consequence of the activity of an area specialized to process words rather than letters, the VWFA.

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REFERENCES

Bentin, S., Allison, T., Puce, A., Perez, E., McCarthy, G., 1996. Electrophysiological studies of face perception in humans. J. Cogn. Neurosci. 8, 551–565.
Black, S.E., Behrmann, M., 1994. Localization in alexia. In: Kertesz, A. (Ed.), Localization and Neuroimaging in Neurospychology. Academic Press, London, pp. 331–376.
Bruce, V., Young, A., 1986. Understanding face recognition. Br. J. Psychol. 77, 305–327.
Caplan, D., 1996. Language: Structure, Processing, and Disorders. MTI Press, Cambridge.
Chapman, R.M., McCrary, J.W., 1995. EP component identification and measurement by principal component analysis. Brain Cogn. 27, 288–310.
Cohen, L., Dehaene, S., Naccache, L., Lehericy, S., Dehaene-Lambertz, G., Henaff, M.A., Michel, F., 2000. The visual word form area: spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. Brain 123, 291–307.
Dehaene, S., 2005. Evolution of human cortical circuits for reading and arithmetic: the "neuronal recycling" hypothesis In: Dehaene, S., Duhamel, J.-R., Hauser, M.D., Rizzolatti, G. (Eds.), From Monkey Brain to Human Brain. MIT Press, Cambridge (Ma), pp. 133–158.
Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J.-F., Poline, J.-B., Rivière, D., 2001. Cerebral mechanisms of word masking and unconscious repetition priming. Nat. Neurosci. 4, 752–758.
Démonet, J.-F., Thierry, G., Cardebat, D., 2005. Renewal of the neurophysiology of language; functional neuroimaging. Physiol. Rev. 85, 49–95.
Dien, J., Frishkoff, G.A., Cerbone, A., Tucker, D.M., 2003. Parametric analysis of event-related potentials in semantic comprehension: evidence for parallel brain mechanisms. Cogn. Brain Res. 15, 137–153.
Ellis, A.W., Young, A.W., 1996. Human Cognitive Neuropsychology, 2nd ed. Psychology Press, LEA, Hillsdale (NJ).
Hauk, O., Davis, M.H., Ford, M., Pulvermüller, F., Marslen-Wilson, W.D., 2006. The time course of visual word recognition as revealed by linear regression analysis of ERP data. NeuroImage 30, 1383–1400.
Hinojosa, J.A., Martín-Loeches, M., Gómez-Jarabo, G., Rubia, F.J., 2000. Common basal extrastriate areas for the semantic processing of words and pictures. Clin. Neurophysiol. 111, 552–560.
Hinojosa, J.A., Martín-Loeches, M., Casado, P., Muñoz, F., Carretié, L., Fernández-Frías, C., Pozo, M.A., 2001a. Semantic processing of open and closed-class words: an event-related potentials study. Cogn. Brain Res. 11, 397–407.
Hinojosa, J.A., Martín-Loeches, M., Casado, P., Muñoz, F., Fernández-Frías, C., Pozo, M.A., 2001b. Studying semantics in the brain: the rapid stream stimulation paradigm. Brain Res. Protocols 8, 199–207.
Hinojosa, J.A., Martín-Loeches, M., Muñoz, F., Casado, P., Fernández-Frías, C., Pozo, M.A., 2001c. Electrophysiological evidence of a semantic system commonly accessed by animals and tools categories. Cogn. Brain Res. 12, 321–328.
Hinojosa, J.A., Martín-Loeches, M., Muñoz, F., Casado, P., Pozo, M.A., 2004. Electrophysiological evidence of automatic early semantic processing. Brain Lang. 88, 39–46.
Iglesias, A., Martín-Loeches, M., Hinojosa, J.A., Casado, P., Muñoz, F., Fernandez-Frias, C., 2004. The recognition potential during sentence presentation: stimulus probability, background stimuli, and SOA. Int. J. Psychophysiol. 52, 169–186.
James, K.H., James, T.W., Jobard, G., Wong, A.C.-N., Gauthier, I., 2005. Letter processing in the visual system: different activation patterns for single letters and strings. Cogn. Affect. Behav. Neurosci. 5, 452–466.
Kutas, M., 1997. Views on how the electrical activity that the brain generates reflects the functions of different language structures. Psychophysiology 34, 383–398.
Marí-Beffa, P., Valdés, B., Cullen, D.J.D., Catena, A., Houghton, G., 2005. Erp analyses of task effects on semantic processing from words. Cogn. Brain Res. 23, 293–305.
Martín-Loeches, M., Hinojosa, J.A., Gómez-Jarabo, G., Rubia, F.J., 1999. The recognition potential: an ERP index of lexical access. Brain Lang. 70, 364–384.
Martín-Loeches, M., Hinojosa, J.A., Fernández-Frías, C., Rubia, F.J., 2001a. Fuctional differences in the semantic processing of concrete and abstract words. Neuropsychologia 39, 1086–1096.
Martín-Loeches, M., Hinojosa, J.A., Gómez-Jarabo, G., Rubia, F.J., 2001b. An early electrophysiological sign of semantic processing in basal extrastriate areas. Psychophysiology 38, 114–124.
Martín-Loeches, M., Hinojosa, J.A., Casado, P., Muñoz, F., Fernández-Frías, C., 2004a. Electrophysiological evidence of an early effect of sentence context in reading. Biol. Psicol. 65, 265–280.
Martín-Loeches, M., Muñoz, F., Casado, P., Hinojosa, J.A., Molina, V., 2004b. An electrophysiological (ERP) component, the recognition potential, in the assessment of brain semantic networks in patients with schizophrenia. Schizophr. Res. 71, 393–404.
Martín-Loeches, M., Sommer, W., Hinojosa, J.A., 2005. ERP components reflecting stimulus identification: contrasting the recognition potential and the early repetition effect (N250r). Int. J. Pshychophysiol. 55, 113–125.
McCandliss, B.C., Cohen, L., Dehaene, S., 2003. The visual word form area: expertise for reading in the fusiform gyrus. Trends Cogn. Sci. 7, 293–299.
Mechelli, A., Price, C.A., Friston, K.J., Ishai, A., 2004. Where bottom-up meets top-down: neuronal interactions during perception and imagery. Cereb. Cortex 14, 1256–1265.
Nobre, A.C., Allison, T., McCarthy, G., 1994. Word recognition in the human inferior temporal lobe. Nature 372, 260–263.
Price, C.J., 2000. The anatomy of language: contributions from functional neuroimaging. J. Anat. 197, 335–359.

Price, C.J., Devlin, J.T., 2003. The myth of the visual word form area. NeuroImage 19, 473–481.
Pu, J., Peng, D., Demaree, H.A., Song, Y., Wei, J., Xu, L., 2005. The recognition potential: Semantic processing or the detection of differences between stimuli? Cogn. Brain Res. 25, 273–282.
Pulvermüller, F., 2001. Brain reflections of word and their meaning. TICS 5, 517–524.
Rudell, A.P., 1990. The recognition potential: a visual response evoked by recognizable images. Abstracts - Neuroscience 16, 106.
Rudell, A.P., 1991. The recognition potential contrasted with the P300. Int. J. Neurosci. 60, 85–111.
Rudell, A.P., 1992. Rapid stream stimulation and the recognition potential. Electroencephalogr. Clin. Neurophysiol. 83, 77–82.
Rudell, A.P., 1999. The recognition potential and the word frequency effect at a high rate of word presentation. Cogn. Brain Res. 8, 173–175.
Rudell, A.P., Hu, B., 1999. Effects of target area and letter complexity on event-related potentials and reaction time. Int. J. Neurosci. 99, 159–180.
Rudell, A.P., Hu, B., 2001. Does a warning signal accelerate the processing of sensory information? Evidence from recognition potential responses to high and low frequency words. Int. J. Psychophysiol. 41, 31–42.
Rudell, A.P., Hua, J., 1995. Recognition potential latency and word image degradation. Brain Lang. 51, 229–241.
Rudell, A.P., Hua, J., 1996a. The recognition potential and word priming. Int. J. Neurosci. 87, 225–240.
Rudell, A.P., Hua, J., 1996b. The recognition potential and conscious awareness. Electroencephalogr. Clin. Neurophysiol. 98, 309–318.
Rudell, A.P., Hua, J., 1997. The recognition potential, word difficulty, and individual reading ability: on using event-related potentials to study perception. J. Exp. Psychol. Hum. Percept. Perform. 23, 1170–1195.
Rudell, A.P., Cracco, R.Q., Hassan, N.F., Eberle, L.P., 1993. Recognition potential: sensitivity to visual field stimulated. Electroencephalogr. Clin. Neurophysiol. 87, 221–234.
Rudell, A.P., Hu, B., Prasad, S., Andersons, P.V., 2000. The recognition potential and reversed letters. Int. J. Neurosci. 101, 109–132.
Schendan, H.E., Ganis, G., Kutas, M., 1998. Neurophysiological evidence for visual perceptual categorization of words and faces within 150 ms. Psychophysiology 35, 240–251.
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.
Skrandies, W., 1998. Evoked potential correlates of semantic meaning—A brain mapping study. Cogn. Brain Res. 6, 173–183.
Valentine, T., Moore, V., Brédart, S., 1995. Priming production of people's names. Q. J. Exp. Psychol., A 48, 513–535.