Exploring the mental lexicon: a methodological approach to understanding how printed words are represented in our minds

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Language comprehension implies isolating words, extracting their meaning and understanding the rules according to which words are combined in sentences. Words are sound-to-meaning representations from spoken language and grapheme-to-phoneme-to-meaning representations from written language. The pool of words that we store in our cognitive system throughout our life experience and that we access for comprehending spoken and written language is known as the mental lexicon. The mental lexicon comprises phonological and orthographic representations, that is, abstract structures shaped in our cognitive system from specific visual features from print and auditory features from speech. Consequently, a lexical entry is a mental abstraction of a word where its orthographic and phonological features and semantic meaning are uniquely represented (Frost, 1998). Thus, when a word is visually presented, the lexical entry of this word is automatically reached via the activation of its representation. This simple principle is essential in understanding how written words are represented and processed in the mental lexicon.

Visual word recognition is a principal stage in reading. How words are stored and accessed in our mind/brain has been a focus of intense research interest. In this chapter we will examine the processes involved in written word recognition from a methodological perspective. What happens from the moment our visual system perceives a word until our cognitive system identifies it? We will describe several sophisticated techniques that have been used to investigate the nature and the time course of this fascinating process, as different methodologies focus on different aspects of processing using a variety of measures. Thus, we will present an overview of what identifying a word means and how this has been investigated so far. We will describe how different technologies are used to explore the factors that enhance or hinder word identification and the time course of the perception, activation and selection of a word. In addition, we will depict how our knowledge about these and other questions is advanced. Since the time course of visual word recognition is a central issue in this review, we will not include data collected with techniques such as fMRI (functional magnetic resonance imaging) or cortical stimulation, but will focus on behavioral techniques and the recent use of EEG (electroencephalograpy).

Basic processes involved in word identification

To be correctly identified, a word has to be perceived and differentiated by the visual system from any other nonlinguistic visual stimulus. For this to happen, the system needs to perceive a group of letters and integrate the invariant information about the structure of the word in a perceptual unit (McCandliss, Cohen & Deahene, 2003). Once the system has perceived that the visual input is a word, several exhaustive coding processes take place to identify it, that is, to differentiate it from all the possible existing words. We will primarily focus on this stage of word identification, giving a brief methodological description of how different paradigms account for the so called pre-lexical (previous to word selection) and lexical (during word selection) processes.

According to the evidence, there are two basic processes that work together for the successful identification of a word: orthographic and phonological processes. When the reader encounters a word, the visual orthographic input is coded first: letters are identified and their position coded across the letter string. Based on orthographic information, the phonological computation process takes place. This process maps the activated letters with the corresponding phonemes, matching the orthographic representation with the corresponding phonological representation. Thus a) the cognitive system works with two interdependent representations shaped as a result of speaking and reading experience: phonological and orthographic representations, respectively, b) the accurate identification of a printed word involves reliance on visual orthographic cues: only if we code the string of letters we will be able to match the input word with the correct representation in our mental lexicon, c) phonology plays a central role in the word selection mechanism in that it aids orthography to settle the constraints of what possible word is being identified.

There are two classical tasks that have helped to examine the dynamics of lexical access: these are the lexical decision and the reading aloud tasks. Using these tasks, essential information about how words are accessed in the lexicon has been obtained. For example, high frequency words are easier to recognize than low frequency words (Balota and Chumbley, 1984) because high frequency words are more strongly represented in the lexicon than low frequency words. Similarly, words with higher frequency neighbors (orthographically similar words higher in frequency than the one presented) are more difficult to recognize than words with lower frequency neighbors (Carreiras, Perea & Grainger, 1997; Grainger, 1990; Davis, Perea and Acha; 2009) because in the first case there are several activated representations competing for selection. Each task comes with its own bias. In the lexical decision task words and nonwords are presented randomly on a screen and the subjects have to say whether what they see is a word (pressing a "yes" button) or a nonword (pressing a "no" button). In the reading aloud task, words are presented on the screen and the subjects have to read them aloud. Both tasks imply access to the lexicon although they may reveal different sub-processes. In the lexical decision task, reaction times and percentage of errors may reflect more the processes involved in lexical selection and decision. However, in the naming task reading times can reflect more the processes involved in phonological recoding and production. This is an example of how some classical tasks can inform about word identification mechanisms. In the same way, other different experimental paradigms have been used to establish how words are perceived (perceptual processes), how and when orthographic and phonological coding processes take place (sub-lexical processes), and why, once coded, some words are easier to identify than others (lexical factors).

1. Behavioral evidence

1.1. The perception of printed letters: the letter search task

One of the very first steps in any identification process is the perception of the visual features of the stimulus. In the case of words, the system must perceive a group of letter features that become more distinct over time. This low-level process occurs at the earliest stages of word identification and can be captured by tasks tapping into perceptual analysis of the visual features of the stimulus. To capture these early perceptual effects, researchers have used paradigms that involve the short presentation of a target stimulus and a response that does not require lexical access, such as the letter search task.

In the letter search task participants have to identify a pre-specified letter and then decide whether it is embedded in a briefly presented letter string. Usually, participants are presented with a letter for 750 ms, and then a forward mask consisting of a row of hash marks matched in length with the target word is presented for 500 ms. The function of the mask is to avoid perceptual overlap between the letter and the word. The mask is then replaced by the target word that remains on the screen until the response. Participants have to decide as fast as possible whether the previously presented letter is or is not in the target word.

This task is designed to capture the sensitiveness of the visual system to the orthographic structure of words, since orthographic analysis of the visual feature in the input word is required to detect the letter, without focusing on which word it is, or its meaning. Thus, the observed search function is thought to reflect low level-perceptual processes used by participants when carrying out the task. This search function is the result of the detection reaction time or error rate for each letter in different positions across the string. So, if initial letter detection takes less time than central of final letters, the visual search function will show and ascendant pattern reflecting a serial left-to-right perceptual strategy, whereas, if central letters are easier to detect than the others, that might indicate that the reader is using a global strategy to extract the orthographic information the word. Based on this assumption, empirical evidence manipulating the position of the cue letter in the target string has suggested that there is a relation between the search function of the letter and the orthographic properties of a given language. Several studies conducted with English participants using nonword targets have shown that the activation pattern of the letter string mimics the orthographic regularities of the language, and that the visual system is sensitive to these regularities. For example, Green et al. (1983) found that the letter search function obtained in alphabetic orthographies was M shaped, whereas the function obtained for logographic strings was U shaped. They concluded that the search function reflects procedures adapted to the demands of the orthographic script (see Green and Meara, 1987; Ktori and Pitchford, 2008; Ziegler and Jacobs, 1995). According to this, the perceptual strategy seems to be modulated by the orthographic nature of the language. Additionally, the visual system also seems to be sensitive to its orthographic regularities. For example, more recently, Pitchford et al. (2008) observed that the visual word recognition system was sensitive to statistical learning; more specifically, the search function in English was dependent on positional letter frequency.

In the same way Acha and Perea (2010) used this task to test the contribution of consonants and vowels to the formation of orthographic structures in Spanish. If the perceptual system is sensitive to statistical regularities of the language, Spanish subjects should show sensitiveness to the CV structure with a different search function for consonants and vowels, since consonants are more frequent in the first position and vowels are more frequent in the last position in this language. This letter search experiment was conducted with words and non-word letter strings and for both the letter search pattern was ascendant for consonants (subjects required less time to detect a consonant when it was in the first position compared to the central and last positions), and descendant for vowels (subjects required less time to detect a vowel in the last position compared to the first and central positions). These results reflect that: a) readers have a representation of the skeletal CV structure of the words in their language, as a result of learning statistical regularities, b) the perceptual processes that take place during the first moments of word identification are sensitive to this structure, and c) the effect reflects processes that are free from lexical influence, since the same pattern is obtained when searching for the letter in words and in non-words.

Despite the suitability of this task for capturing perceptual sensitiveness to the orthographic constitution of words, there is interesting evidence for the assumption that phonological properties of words can also induce early perceptual effects. Ziegler and Jacobs (1995) tested this issue by asking subjects to detect whether a letter was present or absent in a briefly presented target string. This target could be: a) a word -detect the H in BAHN, BOOT-, b) a nonword -NFHX, DSKM-, c) a pseudohomophone -BAAN, BOHT-, c) a control pseudoword -BAAS, BIHT-. Hence, the pseudohomophone could include the letter that was absent in the written word (detect the "I" in TAIP-"tape") or not (detect the "I" in BRANE –"brain"). Detection times were longer in the pseudohomophone condition, with more miss errors (say "no" when the response is "yes") in the first case, and more false alarm errors (say "yes" when the response is "no") with respect to the control conditions. This effect occurred because the phonological representation of the pseudohomophone was activated from the printed array, invoking the lexical entry of its corresponding orthographic form ("brain", "tape"). Resolving the conflict between the two possible candidates (activated, real) generated the pseudohomophone condition disadvantage. This experiment provided robust evidence that during perceptual processing of words the cognitive system extracts invariant information about their orthographic structure, but also, to some extent, about their phonological properties.

1.2.The perception of printed words: the same-different task

There is a variation of the letter search task that involves lexical access. It has been used to account for word perception effects eliciting a response based on whole word analysis instead of a letter by letter analysis. This procedure consists of presenting a fixation point in the middle of the screen for 500 ms, followed by a stimulus display that consists of two arrays of letters one above the other. Subjects have to decide as soon as possible whether the two arrays have a letter in common or not, pressing a "yes" or no" button respectively (Rattcliff, 1981; Van Zandt, Colonius, and Proctor, 2000). The response here is based on the physical similarity between the two arrays. Using this procedure, Kreuger (1989) showed that subjects were faster when the pairs were words than when the pairs were nonwords. This was taken to indicate that the task involved lexical access to some degree. Besner, Smith and MacLeod (1990) also found that the response was slower when the two word pairs were semantically related than when they were unrelated. The activation of semantics through perception seemingly increased the focus of attention at the semantic level, making it more difficult to attend and process the component letters. In sum, these results can be taken as evidence that this variant of the search task taps into processes taking place when the visual analysis is performed at the word level, implying a degree of lexical access.

It is also possible to increase the level of lexical access in this task by changing the type of response, such as asking participants to decide whether the two words are the same or different (instead of deciding if they have a letter in common or not). One item (called the reference) is presented on the screen for around 750 ms and after that, the target is presented until the response is given. This way an analytical processing of words (focusing on the letters) is replaced by a more holistic or/and deeper processing (focusing on the general features or/and the content of the two stimuli).

Meyer and Schvaneveldt (1971) used this task to examine lexical activation with this procedure. In the first experiment subjects had to press “yes” if the two arrays presented were words, and “no” if the two arrays presented were nonwords or a word and a nonword. The “no“response in the former case was as fast the “yes” response. However, the “no” response was slower when the first component of the array was a word (word-nonword) than when it was a nonword (nonword-word). This was the case because when the first string presented was a word, the activation of its representation was so high that it hindered comparison with the nonword much more than when the first string was a nonword. To check if lexical access at this perceptual level was primarily driven by orthography, Besner, Coltheart and Davelaar (1984) used the same procedure including a condition in which the first word was presented in lower case and the target word in capital letters (cross-case same-different task). Participants had to respond “same” to physically identical letter strings (HILE-HILE). When the two words presented shared phonology and orthography (hile/HILE) the “different“ decision was more difficult than when words shared phonology but not orthography (hyle/HILE). In fact, this pair was not slower than control pairs that differed in both orthography and phonology (hule/HILE). Thus, the early perceptual, orthographic and phonological processes involved in the activation of lexical representations can be made visible in responses to tasks by triggering visual analysis of the string. See also Duñabeitia et al. (2012) for the use of this taks to investigate transposed letter effects.

1.3.Orthographic and phonological activation in word recognition: the masked priming technique

The effects obtained in the same-different tasks suggest that the perception of a printed word is able to activate the internal abstract representation of that word in the mental lexicon, so that the presentation of a word or a nonword above the target has a distinct impact on its identification. However, in this paradigm both items are visible and the correct response can be driven by a shallow analysis of the two items. One way to test whether the activation of an abstract representation of a stimulus is accumulative in time and how this activation impacts on the recognition of a subsequent stimulus is the masked priming paradigm developed by Forster and Davis (1984). In the masked priming technique, two items are presented one immediately after the other. The first stimulus, called the prime, is presented for a very brief time to prevent conscious awareness but long enough to be captured by the visual system (this normally ranges from 30 to 60 ms) followed by the target that participants have to respond to. Each trial starts with a row of hash marks displayed for 500 ms (forward mask). Afterwards, the first item is presented in lowercase for about 50 ms and when this item disappears the second item is displayed on the screen in uppercase to avoid visual-physical overlap between the two words. If the prime is able to activate its abstract representation, this will have an impact on the selection of the representation of the target, since two representations will be active at one time. Evidence supporting the activation of an abstract representation in the lexicon is that mixed-case primes (dEnTiSt –DENTIST) are just as effective as pure-case primes (dentist-DENTIST) in masked priming experiments (Forster and Guess, 1996; but see also Rayner, Well, and Pollatsek, 1980; for evidence with eye movements; and Bowers, Bub, and Arguin, 1996; for neuropsychological evidence).

The relevant issue here is that manipulating the prime-target relationship (that is, holding the target constant and manipulating certain aspects of the prime) can be used to explore how certain properties of the prime, such as phonological, orthographic or semantic similarity, have an impact on the recognition of the target. Variations on the recognition times of the target shall be due to the manipulated properties of the prime. For instance, when the properties of the prime are very similar to those of the target, target identification is facilitated, due to the strong expectancy generated by the representation activated by the prime towards the target´s representation. The clearest example is the form effect: when subjects are asked to identify a word, this word is identified faster when preceded by a prime similar to it as compared to an unrelated word (horse-HOUSE, vs. faith-HOUSE; Forster, Davis, Schoknecht and Carter, 1987). This procedure has been very effective to tap early automatic and strategy-free processes involved in lexical activation, since subjects do not consciously take the prime into account when making a decision about the target stimulus. Because of its potential, this task has been broadly used to investigate both orthographic and phonological processes that take place prior to the selection of the lexical entry in word recognition. Nonetheless, it can be used and it has been used to investigate also other processes such as semantic representation or effects of sublexical units (Carreiras & Perea, 2002; Pexman, Lupker, & Hino, 2002).

The *masked priming lexical decision task* has provided evidence about basic processes such as how we code letters to start generating a word representation, or how we use orthographic or phonological information from the input string to activate a word in our lexicon. If we consider the orthographic coding stage, this task has shown that a prime which contains the same letters of the target but jumbled or transposed can activate the target representation. For instance, Forster, Davis, Schocknecht and Carter (1987) examined how the degree of orthographic similarity between prime and target influences the recognition of the target. They used four types of nonword primes: identity primes (answer-ANSWER), transposed letter primes (anwser-ANSWER), substitution primes (ansmer-ANSWER) and an orthographically nonrelated control (orclid-ANSWER). They found that words were identified equally fast when preceded by an identity and by a similar prime (see also Humphreys, Evett and Quinlan, 1990; Shoonbaert and Grainger 2004), and the orthographic similarity effect was similar for low frequency and for high frequency words. This was so for the words belonging to low density neighborhoods –implying lack of competition-. Taking into account that the SOA used in the experiment was

60 ms (the timing between the onset of the mask and the prime is called SOA or Stimulus Onset Asynchrony), and that high frequency word primes should have been activated faster, the authors assumed that in such priming conditions the entry of the prime might be accessed before the same entry was accessed by the target. However, as priming effects increase linearly from prime durations of 30 to 100 ms, the lack of effect in the high density neighborhood could be related to the fact that in this condition, many candidates were activated by the prime, so that no selection took place in the 60 ms so that activation or possible primes and target merged in time. The transposed letter effect was revisited and replicated by Perea and Lupker (2004), who also showed that this effect occurs even when two nonadjacent letters are transposed in the prime (caniso-CASINO vs. caviro-CASINO; Perea and Lupker, 2004). This finding shows that a prime which is similar to the target can facilitate its identification due to the activation of its representation. Similarly, this task has also shown that a prime with a few letters of a word are able to activate this word, no matter the position of these letters: The prime blcn facilitates the target BALCONY in the same way the prime b_lc_n does (Peressotti and Grainger, 1999), and the primes a-ric-t and arict facilitate APRICOT in the same way (Grainger et al., 2006). These relative position priming effects have been demonstrated only when primes are consonants, but not when they are vowels, adding evidence to the differential role of consonants and vowels during visual word recogntion (Duñabeitia & Carreiras, 2011). Both “transposed letter” and “relative position coding” effects have been crucial in understanding how our cognitive system encodes letters to create an orthographic representation: the visual system needs to identify the letters previous to identifying their position. In addition, a word representation can be activated by just a few letters and these letters do not have to be coded in an absolute position. The cognitive system is flexible enough that a word-like string drives activation from the orthography to the representational level to activate the real word. In addition, this flexibility is greater when lexical items are not yet strongly represented in the lexicon, which is why these facilitative form effects are stronger in children than in adults (see Acha and Perea, 2009; Castles Davis, Cavalot and Forster, 2007).

The masked priming lexical decision task has also revealed the impact of phonological processes during visual word recognition. Primes phonologically similar to the target activate the phonological representation of a word, facilitating its recognition. Perfetti and Bell (1991) showed that when a target was preceded by a pseudohomophone (a letter string that shares phonology with an orthographically different target, mave-MOVE) it facilitated the recognition of the target compared to a control pseudoword (fand-MOVE) when the prime duration was settled at 65 ms. Ferrand and Grainger, (1992,1993) and Grainger and Ferrand (1996) replicated and extended this result varying the prime duration from 17 to 100 ms. They found that orthographic priming (nerc-NERF) produced a facilitative effect with a SOA of 33 ms, but phonological priming (nair-NERF) started to emerge only at a 55 ms SOA.

This assumedly reflects that phonology, as well as orthography, is a mandatory process in the activation of a lexical entry in the cognitive system, and that this happens very early, presumably just after orthographic coding has started. Further evidence was provided by Pollatsek, Perea and Carreiras (2005). They manipulated the context dependent letter “c” in Spanish and showed that prime target pairs that involved a phonological change (cinal-CANAL, /z/-/k/) were recognized slower than pairs that did not imply such change (conal-CANAL, /k//k/), with respect to their orthographic controls (pinel-PANEL, ponel-PANEL) at 60 ms SOA. One additional and interesting finding comes from a study by Carreiras, Ferrand, Grainger and Perea (2005) who compared the recognition times of words preceded by a phonologically similar prime by the first syllable (fomie-FAUCON) with respect to a substitution control (fémie-FAUCON) with words preceded by a phonologically similar prime by the second syllable (retôt-GATEU) with respect to a substitution control (retin-GATEAU). Phonological priming occurred only in the first case, implying that phonological processing might be sequential.

Using words instead of nonword as primes allow us to investigate not only processes occurring during lexical activation but also during lexical selection. This way it can be tested how lexical factors related to the prime, such as word frequency and number of neighbors, can affect the way a word is selected in the lexicon. Segui and Grainger (1990) found out that unmasked word primes that were lower in frequency than their targets facilitated their recognition, whereas higher frequency primes did not produce any effect, but when masked and presented with a 50 ms SOA, high frequency primes produced inhibition of the target identification. Prime frequency could be considered a good lexical measure to activate a candidate in the lexicon which persists during perception and activation of the target. As high frequency items are stronger stored in memory, its activation should be greater and its inhibition more difficult. As a result a high frequency prime will be more activated and compete more with the target during the selection process than a low frequency prime. Hence, the different pattern of effects reflects different levels of processing: activation of the representations on the lexicon on the one hand, and selection of the proper one among the ones activated on the other hand. This competition for selection process has been further explored using the neighborhood frequency, rather than the frequency itself, as a lexical measure. Similar words of higher frequency than the one to be identified inhibit its identification. This inhibitory effect of high frequency neighbors has been replicated and extended to many languages and to different similarity levels (de Moor and Brysbaert, 2000; Davis, Perea & Acha, 2009). Not only substitution neighbors (words differing by one letter like cosa-casa) can inhibit the identification of a word, but also addition (fecha-flecha), deletion (sueldo-suelo) and sometimes transposition neighbors (guarida-guardia, see Andrews, 1996). Finally, semantic effects are also important in early stages of visual word recognition. Since Meyer and Schvaneveldt (1971) found that semantically associated pairs are recognized easier that non associated pairs, many studies have devoted to examine how semantics affects word recognition using the semantic priming technique.

Concretely, using the masked priming lexical decision task, Perea and Rosa (2002) run an experiment in Spanish in which they found that the semantic relationship between a word prime and a target word also facilitates its recognition compared to an unrelated prime condition, although with a longer SOA than usual. Using different prime durations (SOA of 66, 83, 100, and 116 ms) they found that in Spanish, highly associated semantic pairs (synonyms: country-NATION, antonyms: war-PEACE, category pairs: table-CHAIR) produced facilitation compared to unrelated conditions even in the shortest SOA. However, when the semantic pairs where no associated: (boat-VESSEL, order-CHAOS, cat-RABBIT), effects were obtained with a 83 ms SOA or longer. In sum, those experiments show that even access to semantics can be mediated by the properties of the prime during early stages of word recognition, so that access to a word in our lexicon a) lags on ortho-phonological properties of the word, and b) is modulated by the distinct semantic relationships that such word represents in the environment. Therefore, the masked priming procedure can help to explain how orthographic, phonological and semantic properties of words are connected in our mental lexicon as well as the time course of these processes. There is still a big debate about how these properties interact during word identification depending on the orthographic, phonological and semantic properties of each language.

1.4.Variants of masked priming: the cross case same-different and lexical decision tasks

After the seminal and more standard masked priming lexical decision task (Forster & Davis, 1984) other variations of this task have been proposed to increase its sensitivity to particular processes.

A very recent variant of the masked priming technique is the so called *sandwich priming* (Lupker and Davis, 2009). The only difference with respect to the traditional technique is the brief presentation of the target prior to the presentation of the prime. The rationale is that the introduction of the target at the beginning of the presentation reduces lexical inhibition because of the activation of two potential candidates, and enhances bottom up effects of the prime (that is, effects occurring previous to lexical access). S*andwich priming* seems to make prime-target similarity effects stronger, and can be particularly good in those cases in which effects with the traditional masked priming paradigm are not strong, as happens with the form effect when the degree of dissimilarity between prime and target is large (see Guerrera and Forster, 2008).

Another variant is the so called *cross case masked priming same-different task* which has been proposed as more sensitive to early perceptual levels of word identification. This variant of the traditional same different task has recently started to be used based on the assumption that the masked priming technique breaks down the perceptual process, since prime and target can be perceived as a single object. The task responded to the concern about the real influence of the prime over the target during this first moment of visual perception, in other words, about the pattern of priming at the perceptual level, in order to understand how the information of the prime is combined with the information of the target at such stage (Norris & Kinoshita, 2008). In this task participants are asked to decide whether the target is the same or different from a reference -also presented before. The reference is presented in lowercase for about 750 to 1000 ms above a forward mask consisting of a series of hash signs. When the reference disappears the forward mask is replaced by the lowercase prime for 50 ms, which is then replaced by the uppercase target (which can remain on the screen for 2000 ms or until response). Due to the fact that the prime is not visible, and that it differs in case with the target, this task goes beyond low-level perceptual similarity effects and seems to have the potential advantage to capture non-lexical orthographic processes driven from the activation of abstract letter identities in the prime. That is, the prime should be equally effective for words and nonwords. Norris and Kinoshita (2008) tested the properties of the task, showing that priming effects were effective both for words and nonwords in the "same" trials (able-able-ABLE/ebla-ebla-EBLA) but not in the "different" trials (reed-able-ABLE/rera-able-ABLE). Having seen that the "same" trials were able to capture form priming effects, Kinoshita and Norris (2009) further examined the extent to which these trials were able to capture orthographic and phonological effects. Comparing identity (score-score-SCORE), pseudohomphone (score-skore-SCORE) and control primes (score-smore-SCORE), they found that only the identity prime facilitated the same response and concluded that the priming effect obtained in this task is mainly orthographic. They also examined to what extent the perceived input needs to be exhaustively coded to activate the lexical representation, comparing a transposed letter (faith-fiath-FAITH), a two letter substitution (faith-fouth-FAITH), a scrambled prime (faith-ifhat-FAITH) and a totally different control prime (faith-knock-FAITH). The transposed letter prime facilitated the "same" response as compared to the other conditions, but the more different the prime was to the target, the slower the response. In addition, effects obtained at this level are blind to letter status (equal effects when the transposed letters are consonants –*retpil*- or vowels -*craota*-, Perea & Acha, 2009), or to morpheme units –*walekr* and *brotehl* equally prime their respective targets *walk**er*** and *broth**el***-, therefore, the letter position coding process might start before any letter or subword unit distinction is made (Duñabeitia et al., 2011).

According to this evidence, it has been assumed that the cross case same-different task is suitable to test orthographic effects that occur at an early perceptual level. However, the controversy of the task comes from the way the activation of the three presented items interacts during the perceptual process. Concretely, it has been observed that the manipulation of the reference-prime and prime-target similitude, the results and therefore the activation triggered by the task. The activation of the prime seems to have a mainly inhibitory effect. This seems to occur because in the "same" trials the target has already been activated by the reference, so that a matching prime (house-house-HOUSE) will imply little additional facilitative activation, whereas an inconsistent prime (house-water-HOUSE) will lead to a "different" response that must be overridden, generating strong inhibitory effects. Perea, Moret-Tatay and Carreiras (2011), examined the effect of reference-prime-target relationship on the same-different response using two presentation modalities and varying the presentation time of the prime. In each experiment there were two levels of manipulation, the explicit one (reference-TARGET relationship leading to "same or "different" response), and the implicit one (prime similarity with respect to reference or TARGET). First, they ran an experiment with the traditional presentation, in which the implicit manipulation focused on the prime-target relationship (prime different to target). Hence, in the "same" condition reference and target were the same (house-**house-HOUSE** vs. house-**water-HOUSE**, in the identity and unrelated prime conditions respectively). In the "different" condition, referent and target were not the same (field-**house-HOUSE** vs. field-**water-HOUSE**, in the identity and unrelated prime conditions respectively). As seen, although the subject needed to focus on the reference-target visual similarity, the experimental conditions (identity and unrelated) were determined by the prime-target relationship. This presentation mode is known as *predictive contingency* because the target can be predicted from the activation of the prime. The most important condition is the identity condition in the "different" trials, in the sense that one can test the inhibitory weight of the reference on the target.

Another experiment was then run, varying the predictability factor, by focusing on the reference-prime relationship. In the "same" condition the reference and target were the same (house-**house-HOUSE** vs. house-**water-HOUSE**, in the identity and unrelated prime conditions respectively). So in the "same" condition this experiment was equal to the first one, but in the "different" condition, the prime was the same to the reference instead of to the target (field-**field-HOUSE** vs. field-**water-HOUSE**, in the related and unrelated prime conditions respectively). This was called *zero contingency* because this time there was no possibility of predicting the target from the prime.

In both experiments, the SOA could be 13, 27, 40, or 53 ms. It was found that for "same" responses both manipulations produced similar results. Greater SOA implied lower reaction times for identity primes (increasing facilitative effect of prime over time), and greater reaction times for unrelated primes (increasing inhibitory effect of prime over time). But for "different" responses the reference-prime relationship did matter. In the *predictive contingency* task, the inhibitory effect decreased similarly when the SOA increased both in the identity (field-**house-HOUSE)** and in the unrelated condition (field-**water-HOUSE)**. This was a sign that the interaction between the activation of the reference and the activation of the target was not affected by the prime. On the contrary, in the *zero contingency* task, the identity condition in the "different" response implied greater inhibition with increasing SOA (field-**field-HOUSE)** as a result of having to inhibit an activated prime, while the unrelated condition (field-**water-HOUSE)** showed the typical decreasing reaction time with increasing SOA. These experiments provide evidence that some caution is necessary when designing cross-case masked priming same-different experiments, as the relation between prime and target and between reference and prime can modulate the examined perceptual effects.

Obviously, with such a diversity of paradigms, a logical question to ask is: which task should be used to investigate the processes involved in the recognition of words?

Because of the potential to capture low level perceptual processes the same-different task should be chosen when low level processes are targeted. However, when the experimenter is interested in capturing higher level sublexical or lexical processes the lexical decision task will supply more information. There are effects that do not occur at a perceptual level but later on, during the activation of the orthographic or phonological representation (and so they are not captured by the same-different task, but are evident in the lexical decision task). One example is the differential effect of vowels and consonants during orthographic activation captured only in the classical masked priming lexical decision task. The "transposed letter" and "relative position" effects do show up for consonants but not for vowels: Perea and Acha (2009) tested the same primes in which the vowels or the consonants in the prime were transposed (retpil-REPTIL vs. craota-CROATA) or replaced (relfil-REPTIL vs. crueta-CROATA). The facilitative TL effect was evident only for the consonants. Also Duñabeitia and Carreiras (2011) have recently shown that the relative position effect occurs when the prime consists of consonants (*csn-CASINO*) but not for vowels (*aio-CASINO*), regardless of the frequency of the letters and the SOA (the effect is equally strong when the prime is presented for 33 and for 50 ms. These effects, as well as phonological effects, are not obtained with the *same different task*, which could indicate that at the level of orthographic coding (but not at an earlier perceptual level) consonants are more crucial in creating the orthographic representation. Finally, the sandwich paradigm should be used to enhance form similarity facilitation in those cases where the standard masked priming paradigm is not powerful enough to produce effects.

1.5.Sub-lexical units in word recognition: from letters to syllables and morphemes

Reading systems involve orthographic and phonological units and a set of mapping rules that determine how orthographic and phonological units are linked to form words. The basic coding units are letters and phonemes. The mapping rules entail a set of combinations of letters and phonemes that, based on mapping regularities, give rise to other structures (e.g., syllables, morphemes, etc). Thus, the cognitive system deals with different types of units that are organized in different levels of complexity. Efficient identification of words can be achieved by combining direct access to the lexicon with these sublexical units. Lexical entries can be accessed sub-lexically through the basic orthographic and phonological units and lexically, making the process of word identification more efficient. Nonetheless, the relative weighting of sublexical units or even the nature of the sublexical unit itself may depend on the novelty of the word and the consistency of phoneme-grapheme correspondences in different languages. For example one likely candidate for Spanish is the syllable.

Carreiras, Alvarez and De Vega, (1993; see also Perea and Carreiras, 1998) tested the role of the syllable as a sublexical unit in word recognition in Spanish, using the single presentation lexical decision task. They used words that began either with a high or a low frequency syllable. Words with a low frequency first syllable were identified faster than words with a high frequency first syllable. They also found that words with higher frequency syllabic neighbors were recognized slower than words with low frequency syllabic neighbors. Later on, using the masked priming technique Carreiras and Perea (2002) found that similar syllabic primes (<u>al</u>to-<u>AL</u>GA) inhibited the recognition of the target compared to control syllabic primes (<u>es</u>to-<u>AL</u>GA), but also that primes that shared the syllabic structure of the target (zo.ta-ZO.CO) produced facilitation with respect to primes that did not share it (ziel-ZO.CO).

From these experiments one could conclude that the syllable is an important sub-lexical unit that operates at a pre-lexical level and that the number of higher frequency syllabic neighbors has an inhibitory effect on word recognition, together with syllable frequency. This seems to be so, particularly in languages with a clear syllabic structure like French (see Colé, Magnan, and Grainger, 1999; Rouibah and Taft, 2001; Conrad, Grainger and Jacobs, 2007). However, in other languages where syllabic boundaries are not marked, other units are more relevant. In English, for example, the so called Basic Orthographic Syllabic Structure BOSS (the largest possible coda in the first component, thund-THUNDER), and not the syllable (thun-THUNDER; Taft and Radeau, 1995; Taft, 2001) seems to operate. Alvarez, Carreiras and Taft (2001) carried out an interesting experiment using lexical decision to test the role of the syllable, BOSS and root morpheme for the identification of Spanish words. When BOSS was kept constant they obtained inhibitory first syllable frequency effect: the frequency of the BOSS in “mad.era” and “hel.ado” is the same, but “madera” requires more time because the syllable “ma” is more frequent than “he”. When the syllable was kept constant there was a facilitative BOSS frequency effect: “pá/l.ido” was identified faster than “pá/j.aro” because “pal” is more frequent than “paj”. However, when the BOSS was kept constant there was a facilitative effect of root frequency: the word “bañador” was identified faster than “batuta” because, the first syllable being the same and the BOSS having the same frequency, the first one has a higher frequency root. The masked priming lexical decision task has also provided evidence that morphemes can be automatically activated during word recognition. For example, a word preceded by a prime that is orthographically and morphologically but not semantically related to the target can activate it (corner-corn) as much as a real morphemic prime (cleaner-CLEAN; Rastle, Davis and New, 2004), implying that morphemes are recognized as functional units at a very early orthographic level. The issue of whether morphemic words are decomposed at an early orthographic level was further pursued by Duñabeitia, Perea and Carreiras (2007; see also Duñabeitia, Perea and Carreiras, 2008) using primes in which the two boundary letters between a lexeme and a morpheme were transposed or replaced using real morphemic words (wakler-WALKER) and non-real morphemic words (brotehl-BROTHEL). With the standard SOA of 50 ms, transposed letter effects were obtained in the second case but not in the first one. However, using the cross-case same different task, Duñabeitia et al. (2011) obtained transposed letter effects in both conditions, showing that morphemes are not processed at a perceptual level, and that they act as functional units for lexical access. In fact, recent research has also shown that the kind of chunks that can be stored to constitute a sub-word unit at a prelexical level depends on the regularities, or the internal structure of the language. Most productive chunks or chunks that appear more often will be easier to retrieve and act as a functional unit compared to combination of letters that do not occur very often, or that are not so regular in the language (See Ziegler & Goswami, 2005). This is why, for example, the derivational morphemic word "mute.vole" (changeable) facilitates the target word "MUTE" (mute) because the overlap between root and target directly leads to the activation of MUTE regardless semantics. And this is why an inflected stem homograph like "muta.rono" (they changed) inhibits the target "MUTE", because the stem is activated and competes with the target while lexical selection is taking place (Laudana, Badecker and Caramazza, 1992). Of course, morpheme productivity and regularity will depend on the nature of the language and its morphological complexity (see Bertram, Laine and Karvinen, 1999; Bertram, Schreuder and Baayen, 2000). In sum, the reported effects show that apart from letters and syllables, the visual system can extract and internalize regularities from the language, which can constitute effective units to drive the process of lexical activation. It remains to be explored how these different "grain sizes" interact or compete during the process of word identification (Ziegler and Goswami, 2005).

2.The time course of the processes involved in word recognition: evidence from eye movements

Technological advances had made available techniques that provide more comprehensive information than the reaction times and number or errors collected with the techniques mentioned before. The possibility of monitoring eye movements while subjects are reading words or sentences displayed on the screen has allowed the use of eye movement measurements for examining the cognitive processes involved in word identification during reading. This technique is more ecological (movements are recorded while the subject is reading silently), and supplies a wide range of early and late measures that can account for the time course of on-line, moment-to-moment reading processes. Unlike behavioral experiments, this task does not require subjects to give a “yes” or “no” answer based on their knowledge of the word or their perceptual ability to match two stimuli. They only have to read while their eye movements are recorded. Thus, it is free of any strategic components derived from additional tasks that could interfere in the process of word identification during the natural act of reading.

There is evidence that orthographic, phonological and semantic properties of the words can influence the way we move our eyes during reading (Rayner, 1998). The most popular procedure for examining this consists of embedding words with certain characteristics that we want to test into sentences. Sentences are displayed one by one and subjects have to read them in silence. Each trial starts with the presentation of a fixation point that is left-aligned, normally coinciding with the location of the first letter of each sentence. After eye calibration, subjects have to gaze at that point and the sentence appears on the screen. When they finish reading the sentence they press a button box to terminate the display and the next fixation point is displayed. To ensure that the subjects are actually reading the sentences for comprehension, a question that has to be responded with a “yes” or “no” button is usually inserted every few sentences. While subjects are reading their eye movements are recorded. Afterwards, the movements that took place in the interesting region (e.g., the word under interest) can be analyzed. When analyzing eye movements, one can take into account either global measures (affecting the whole sentence) or local movements (the ones that took place on a selected area of interest, e.g., a word, a certain noun phrase).

There are several variations of stimuli presentation (eye contingent display change techniques) that help to examine the information readers grasp during reading and the processes involved in identifying words. One of these variations is called the moving window technique that consists of perturbing the text except in a window-region defined by the experimenter. For example, this can be done replacing all the letters with “xxxxx” except for the region that falls in the fovea (the fixated area). This allows analysis of lexical factors, avoiding any information coming from the surrounding areas (that fall in the region called parafovea), or test how much information from the surrounding area can eventually affect word identification. Another variation is the boundary technique, in which a critical target word is initially replaced by another word or nonword until the reader crosses over an invisible pre-specified boundary. When the eye reaches the boundary this stimulus is replaced by the real target word. If the reader is getting parafoveal information from this stimulus, this activated information (as in the priming technique) will affect the identification of the target word, and thus, the eye movement measures on that region.

2.1.Early and late measures as evidence for different processes in word recognition

When we read, we alternate movements across the text with fixations at some points of the text. The movements forward and backward are called *saccades*. The length and duration of the saccades are influenced by the context of the sentence and the difficulty in reading the words (Liversedge and Findlay, 2000). During saccades readers use text cues to integrate partial-word information obtained from the parafovea with the information they get from the fovea when the eyes stop and fixate on a point. The types of cues that help integrate information seem perceptual and based on abstract letter codes. Using the boundary technique Rayner, McConkie and Zola (1980) found that alternating the case of a word when the eye crossed the boundary (preview: cHaNgE/target: ChAnGe) did not affect saccadic measures. This supports the behavioral evidence that words are represented and activated in the lexicon as abstract entities.

In addition, there are periods of time between saccades, in which the eyes pose on certain points and stay still in the word. These are called fixations, and normally last about 200-250 ms. Because eye movements reflect on-line cognitive processes, this average fixation duration constrains the amount of lexical processing. In fact, the number of *fixations* on words, and the duration of these fixations, is modulated by the length and complexity of the word. Short and high frequency words are less fixated than long and high frequency words (Inhoff and Rayner, 1986; Rayner & McConkie, 1976). First fixation duration (the duration of the first time the eye fixates on a word) and *gaze duration* (the duration of all fixations in a word before the eye leaves this word) are thus modulated by lexical factors and reflect early processes that lie beneath the activation of lexical representations. However, it seems that the first measure is more related to early activation processes and the second one also reflects certain integration processes that occur later on (Inhoff, 1984). Supporting evidence for this comes from the root-word frequency effects observed in compound and morphemic words that we will discuss below.

First fixations and gaze durations are called early measures, since they seem to tap onto early lexical activation processes. Nonetheless, there are other measures of eye movements that occur afterwards and that reflect later processes involved in word identification, like competition, integration and selection of the lexical entry. For example, many times readers make movements back to fixate again on points that were already left (this implies a saccadic movement backward). These regressions can be within words (the reader is going back to re-read the word before going to the next word in the sentence) or between words (the reader comes back to a word after having left it previously). The first type of regression reflects problems the reader had processing that word; the second type of regression reflects problems understanding or integrating the text (Murray and Kennedy, 1988). Finally, the total time spent on a word consists of the sum of all fixations on a word (the ones before leaving a region plus the ones that are the result of a regression to that region).

Although most of the words are fixated during reading, some of them are *skipped*, which normally happens with short (Rayner, Sereno & Raney, 1996), predictable (Ehrlich and Rayner, 1981; Rayner and Well, 1996) and function words (Rayner & Duffy, 1988). This is so because when fixating point, the visual information that falls into the area of the fovea is the focus of attention but (as mentioned before) there is also information that falls into the parafovea that is also being processed. In other words, the parafoveal preview assists the foveal processing of the word. Using the moving window technique Rayner et al. (1982) examined the effect of parafoveal processing on word identification, manipulating the number of letters available in the parafovea. This way, the reader could see only the fixated letters with all the letters in the next word being replaced by other letters, the fixated word and the word next to it, or the fixated word with partial information of the word next to it (one, two or three letters). Reading the word was less difficult when at least three letters of the next coming word were available (see also Lima, 1987; White, Rayner and Liversedge, 2005). The lack of parafoveal information causes a detrimental effect of 20 ms on word fixation (Sereno and Rayner, 2000), and when words are skipped, the duration of fixation previous to the skip is inflated (Blanchard, Pollatsek and Rayner, 1989). This implies that letter information is extracted from the parafovea during that fixation, and settles the range of what amount of information can be processed from the incoming word when fixating one word, the so called visual perception span for words.

2.2.Orthographic and phonological activation affect word identification during reading: the parafoveal preview technique

The parafoveal preview technique has revealed orthographic and phonological processes involved in word identification during reading broadening the findings derived from behavioral experiments. For example, orthographic similarity effects have also been obtained with this paradigm. Johnson, Perea and Rayner (2007) examined the effectiveness of the transposed letter effect using identity previews (clerk-clerk), previews that consisted of the transposition of two internal letters of the word (celrk-clerk), and control previews that consisted of the substitution of two internal letters of the word (cohrk-clerk). As in behavioral experiments, transposed letter previews facilitate the identification of the word during reading, so that letter identity is extracted from the parafovea without coding letters in an absolute position, particularly when internal letters are transposed (external letter are anchor points and thus, more important for coding, see Perea and Lupker, 2003, for behavioral evidence).

The same occurs with phonological similarity. Rayner, Pollatsek and Binder (1998) tested the role of orthographic and phonological similarity of a preview in a target word, using four different types of homophones. The preview homophone could be one letter similar to the target (bear-bare), two letters similar to the target (break-brake), it could be a pseudohomophone (brain-brane) and a completely dissimilar word (chute-shoot). They found that the two letters similar homophone preview involved more fixations than the one letter similar homophone. In addition, both homophones and pseudohomophones implied fewer fixations and regression than controls. They concluded that phonology plays an important role in the identification of the word during reading, but so does orthographic information, which is extracted before phonological information comes into play (as reflected in the difference between one and two letter homophones only in first fixation measures).

This support of behavioral findings is also extended to the processing of vowels and consonants. Saccadic movements show that the integration of information during reading is based on abstract letter codes. However, when fixating a word, letters are identified, and both orthographic (earlier) and phonological (later) properties of the words help to activate a certain lexical representation. In this process, vowels and consonants are not processed the same way. Lee, Rayner and Pollatsek (2001) used a paradigm in which the first or two letters of the onset were delayed for either 30 or 60 ms after the moment the eye crossed the boundary for first fixation. At 30 ms, delaying a consonant implied grater gaze durations on the word, but not delaying a vowel, whereas at 60 ms, delaying a vowel or a consonant was equally disruptive. This supports the idea that consonants and vowels play different roles in the coding process of an orthographic representation, consonants playing an earlier and more important role at an early stage of processing.

These effects refer to the processes involved in the activation of a certain representation before lexical selection. But can eye movements reflect the selection of the lexical entry? The dynamics of lexical access have been tested examining frequency and neighborhood frequency effects during reading, based on the assumption that early measures inform about processes involved in early activation of representations and that later measures inform about integration and selection of the lexical entry. We have mentioned that frequency is reflected in the earliest first fixation measure, with high frequency words, which are more strongly activated, being less fixated than low frequency words. This is a direct indication of the difficulty of lexical access. Perea and Pollatsek (1998, but see also Davis, Perea and Acha, 2009) tested the neighborhood frequency effect, embedding target words into sentences. Half of the words had no higher frequency neighbor -hence NHFN (sauce has no similar word in the lexicon with a higher frequency), and half of the words had at least one higher frequency neighbor -hence HFN (spice, that has a higher frequency neighbor space). Subjects saw two counterbalanced sentence frames so that all subjects could see both target words in the same sentence frame. Words with HFN showed similar fixations but more regressions back than words with NHFN, implying that the cost of having a higher frequency neighbor is not at the level of activation, but at the level of selection, due to the competition of various candidates activated at the earliest stage. Recent experiments have focused on how lexical effects can be affected by other variables like predictability from the reading context (Rayner, Slattery, Drieghe, and Liversedge, 2011), the semantic ambiguity, or even the syllabic and morphological structure of words (Pollatsek, Drieghe, Stockall, and De Almeida, 2010).

2.3.Eye movements and sub-word units: Syllabic and morphological effects

Several studies have examined eyetracking data to account for the special role of certain units such as syllables and morphemes during reading. For example, Hutzler Conrad and Jacobs (2005) conducted a single presentation lexical decision task in which eye movements were recorded. They manipulated the frequency of the first syllable in the word to test whether eye movements were sensitive to syllable frequency. Words starting with a high frequency syllable showed an identification cost that was reflected in early measures: first fixations and gaze durations.

Regarding morphemes, evidence comes from studies in which frequency effects of morphologically complex words are examined. These studies have shown that morphemes (derivations, inflections, compounds) are processed as units at the lexical level depending on certain constraints. Based on the evidence that frequency effects of lexical entries are captured by first fixations, Bertram, Pollatsek and Hyona, (2004, see also Niswander, Pollatsek and Rayner, 2000) tested frequency effects of morphologically complex words manipulating the whole word frequency and the root frequency orthogonally. Morphologically complex target words were embedded into sentences, half of them with a high whole word frequency (frequency of the total form), and half of with having a low whole word frequency. In each group the root frequency was manipulated, so that whole words had high frequency and low frequency roots. Interestingly, both whole word and root frequency had an effect. Whole word frequency effects were obtained in first fixations in words with short and unproductive morphemes (this is the typical frequency effect), but words with long and productive morphemes behaved differently. In this case root frequency effects were obtained in first fixations (words with high frequency roots showed less fixations regardless of the whole word frequency), whereas gaze durations reflected whole word frequency effects (whole forms of higher frequency showed lower gaze durations). It is important to note that variables like morphological nature of the language, orthographic structure of words, or morpheme productivity, can modulate the impact of sublexical and lexical processes during word recognition in reading (see Bertram, Hyönä and Laine, 2011). More work is needed to examine how universal processes are modulated by the properties of language in the real reading context in order to provide with a complete theoretical framework of word identification during reading.

<u>3.Neurophysiogical evidence</u>: ERPs

Current development of neurological techniques has established a bridge between the behavioral evidence and the physiology of the brain, trying to describe the neural correlates of the behavioral findings. We now have access to techniques for recording brain activity while subjects perform behavioral tasks. One of these technique is the EEG that provides a detailed temporal track of neuronal activity and is an interesting source to complement the picture offered by behavioral data.

3.1.Temporal resolution of processes involved in word recognition: Event related potentials

The electroencephalogram recording (EEG) technique offers the possibility of tracking the neural response to different cognitive activities on-line with very precise temporal resolution. The EEG allows recording, through sensors located in the scalp, of millisecond-to-millisecond cortical activity generated by the synchronized firing of columns of neurons. The average of this cortical activity through many trials results in an external wave response called an ERP or event related potential. Thus, ERPs are visual and continuous waveform responses reflecting electrical neuronal activity. Waveforms corresponding to different experimental conditions can be compared in three dimensions: amplitude, latency and topography that inform about the size, timing and rough location of the neural activity, respectively. The amplitude can be defined as the size of the peak of the wave resulting from the amount of voltage produced by the neural activity, and it is believed to reflect the amount of resources invested in computing or resolving a certain task. The latency is the time elapsed from the presentation of the stimulus to the peak(s) and is likely to capture the time course of the processes involved in resolving the task. The topography refers to the location of the activity as recorded on the scalp and may reflect the recruitment of groups of different neurons.

Different components have been isolated in the waveforms, and in some cases different cognitive processes have been associated with the modulation of specific components. For example, previous studies have assumed that the ERP wave components that occur at 50-150 ms after the presentation of a stimulus reflect perceptual or visual organizational processes (Foxe and Simpson, 2002). When a word is presented, early visual components are usually modulated (P150/N150). This is much earlier than any behavioral-decisional method can capture. After this first peak, waves reflect sets of peaks due to recurrent feedback processes in the system. These peaks reflect, sublexical effects occurring previous to lexical access at around 150-200 ms post stimulus (e.g., the P150 word repetition effect, see Holcomb and Grainger, 2006; the P200 color-syllable congruency effect, see Carreiras et. al., 2005). The N250 and the N400 are later components that reflect lexical and semantic effects (Neville, Mills, and Lawson, 1992; Barber, Vergara and Carreiras, 2004).

3.2.Perceptual processes and the N170 window

Because of the accurate temporal resolution provided by ERPs, this technique has been combined with the previously described behavioral paradigms to examine the time course of orthographic and phonological processes involved in the activation of lexical representations. The procedure, as in behavioral experiments is to present visual stimuli that vary in certain characteristics and test how the waveform changes according to these characteristics compared to other control conditions. As mentioned, perceptual processes seem to initiate at around 150 ms post stimulus. For example Bentin et al. (1996) and George et al. (1996) showed that differences between symbols and orthographic stimuli like words and pseudowords modulated the N170 peak. In addition, the N150 peak seems to be larger in the left hemisphere for the orthographic stimuli, and it is larger in the right hemisphere for the non-orthographic stimuli (Schendan, Giorgio and Kutas, 1998). This result could be due to two facts: that the left hemisphere is specialized in the characters typical in the alphabetic stimuli or that it is specialized in reading in general. To test this issue, Maurer, Zevin and McCandliss (2008b) carried out an experiment in which two groups of English and Japanese speakers respectively, had to read and detect the repetition in a row of Japanese words written either in syllabic or purely logographic script. English participants showed a N170 effect that was equally high in both hemispheres, whereas Japanese participants showed a left lateralized effect. The authors concluded that the left lateralization is a result of the reading experience and not a reaction to a certain script.

3.3.Orthographic and phonological processes: From the N200 to the N400 window

Soon after the word has been perceived, orthographic information triggers activation to the lexical level, and this is reflected in peaks that go from 200 to 500 ms. For example, orthographic form effects observed in behavioral tasks modulated ERP waveforms in these time-windows (Carreiras et al, 2009; Duñabeitia et al., 2009; Kiyonaga et al., 2006). Concretely, Grainger Kiyonaga and Holcomb (2006) used the masked priming procedure to test whether the activation of the representation of orthographic and phonological primes could be reflected on the ERP waveform. Subjects were presented with words preceded by transposed letter primes (barin-BRAIN) and two letter substitution controls (bosin-BRAIN), and by pseudohomophone primes (brane-BRAIN) and their controls (brant-BRAIN). They observed that both manipulations showed a negative component at 250 ms (N250), although orthographic priming generated a slightly earlier response (at around 200-250 ms) than phonological priming (at around 250-300 ms). Carreiras et al. (2009) also investigated the time course of orthographic and phonological effects in Spanish: the nonword "conal" primed CANAL (/k//k/) more than the nonword "cinal" (/z//k/) compared to pure orthographic controls (ponel-PANEL, pinel-PANEL). Phonological priming in the former case was observed in the 350-550 ms window, whereas orthographic priming in the latter case was observed in the 150-250 ms time window.

This data supports behavioral evidence about the primary role of orthography followed by phonology in the formation of the word representation.

Orthographic and phonological processes affect ongoing processing until at least 500 ms. One example of this is that the N400 can be sensitive to transposed letter effects. Carreiras, Vergara and Perea (2007) found in a single presentation lexical decision task in which pseudowords were created by transposing or substituting two consonants or two vowels of words that transposed letter effects were reflected in the N400. The most interesting finding was that the topographical distribution for vowel transposition (posterior location) was different to that of consonants (anterior location). The same authors (Carreiras et al., 2009) extended this finding using the masked priming lexical decision task (see also Vergara et al. 2011). The peak latency in the N400 was faster for words with transposed letter primes than for words with substitution letter primes, although for vowel transpositions the peak was observed in a earlier window than for consonant transpositions (250 ms and 500 ms respectively). This measure supports the behavioral evidence that vowels and consonants do not contribute in the same way to the activation of mental representation, and that orthographic coding seems to be taking place form the moment of perception until at least 400 ms after onset.

Probably because during this time window some word candidates have been activated, but letter position coding is still taking place, lexical effects are prone to be observed at this time window, previous to lexical selection. In fact, the N400 seems to be especially sensitive to lexical effects. Lexical properties of words such as frequency, neighborhood frequency or repetition have an impact on the ease in selecting a certain representation at this point. When words are presented in a list, seeing a word for the first time -or a word that has been previously repeated in the list- has an impact on the N400 (Besson et al., 1992). Thus this component is sensitive to the extent to which a word is represented and the strength with which it is activated in the lexicon, in sum, with the difficulty in accessing the word. Frequency effects have also been found to modulate the N400, between 300 and 600 ms after words presented in isolation (Bentin et al., 1999; Van Petten and Kutas, 1990). However, when high and low frequency words are presented embedded in sentences, context effects minimize frequency effects (selection of the appropriate item can be deduced by previous context) so that the difference on the waveform at the N400 is smaller (Dambacher et al., 2006). The N400 component is also sensitive to lexical selection processes, as shown by neighborhood effects. Holcomb, Grainger and O´Rourke (2002) tested the effect of neighborhood size in a go-no go lexical decision experiment (press “yes” when you see a word and do not press anything when you see a nonword) in which half of the words had many neighbors and half of the words had few neighbors. Words with more neighbors generated higher peaks in the N400 than words with fewer neighbors. The neighborhood frequency effect was also investigated with words inserted in sentences by Molinaro et al. (2010). Participants had to read sentences that embedded words with and without higher frequency neighbors. Reading the target word implied a N400 effect only when the context was not informative. If the target word was pre-activated by the previous context in the sentence the N400 effect vanished. In sum, this evidence shows that the N400 component can be taken as an index of lexical access and semantic integration.

3.4.ERPs and sub-word units: Syllabic and morphological effects

The time course of activation of units greater than letters has been also investigated with ERPs. Recent evidence has shown that sublexical units such as syllables modulate the P200 component. Barber, Vergara and Carreiras (2004, see also Hutzler et al., 2004) manipulated the word frequency and the syllable frequency in a lexical decision task while recording ERPs. They presented a set of high frequency words and a set of low frequency words with their corresponding nonwords. Half of the words in each set began with a high frequency or a low frequency syllable. As expected, word frequency effects produced less negative amplitudes in the N400, but interestingly, syllable frequency produced the inverse effect in the N400 as well as an effect in the P200. Because of the P200 and the N400 being related to sublexical and lexical activation respectively, the results mean that syllables are activated at the sublexical level and influence the selection of the word at the lexical level. High frequency syllable words imply greater activation early in processing, because of the activation of many candidates that share this first syllable with the target (P200 effect). This implies a harder process of lexical selection later on (N400), because the prospective candidates have to be inhibited to finally identify the correct one. In sum, electrophysiological evidence shows that at a lexical level, word frequency facilitates, but syllable frequency inhibits word recognition due to this activation-competition process.

Likewise, ERP effects have been also reported for other sublexical units like morphemes. Lavric, Clapp and Rastle (2007) replicated and extended the results of their masked priming lexical decision experiment in which root targets were preceded by a real morphemic word (cleaner-CLEAN), a pseudomorphemic word (corner-CORN) and an orthographic control (brothel-BROTH). They found an attenuation of the peak in N400 in the two first conditions compared to the third one, although the type of attenuation varied between the two cases. Morris et al., (2007) extended this finding using the same manipulation and controlling for the amount of semantic relatedness between prime and target. They found reduced amplitude of the N250 and the N400 for the transparent condition compared to the opaque and control conditions, but also a significant linear trend across conditions in the two windows, with the transparent relationship generating the greatest negativity and the orthographic controls the smallest. This implies that morphemic units are activated early during processing, although the balance between orthographic and morphological activation seems to be modulated by semantic transparency.

Summary

Our mental lexicon consists of a pool of words stored in our cognitive system as a result of exposure to spoken and written language. Exploring how these words are recognized from print, can be approached from multiple views and with different methodologies. A good methodological perspective is essential to investigate the processes involved. In this sense, behavioral studies have offered a broad range of paradigms to test automatic processes involved in early word recognition at different levels, from when the visual system perceives the string of letters until orthographic and phonological processes are integrated to activate a certain lexical representation. Perceptual processes seem to be well captured by the same-different task, while sublexical processes and the influence of minor units on lexical access can be well captured with the masked priming technique in different variants. However, the debate persist about the type of influence of the prime on the target, the conditions in which such prime produces facilitation or inhibition, and the duration of this influence. More research is needed to attain a better understanding of the presented effects and to get the complete picture of the word recognition process. Recently new online techniques have become increasingly important in this endeavor. As behavioral techniques tell us about the processing cost of a certain word presented in isolation, eye movement measures inform us about the time course of the processes during silent reading in a natural reading environment. First fixations and gaze durations on a certain word (n) can inform about early sublexical processes whereas amount of regressions and total times reflect competition processes for the selection of a lexical candidate. The impact of perceptual processes in the parafovea on word reading can also be examined, either with the preview technique or analyzing the impact of the previous word on the subsequent one (n-1). Also postlexical proceses can be examined focusing or the impact of the word of interest on the next one (n+1). Although the amount of evidence has not been as vast as in the behavioral field, eye movement measures are providing a framework for the time course of the processes previously studied behaviorally, in a much more ecological context. Most recent research has focused on the neural correlates of the behavioral findings. Electrophysiological measures provide rich data and precise on-line temporal resolution of the neural activity triggered by the processes under study. This field is providing more subtle evidence about the time course of sublexical and lexical process and the specific components related to them. The novelty of the techniques and the diversity of paradigms still leave the door open to caveats, though. Techniques should take behavioral designs and paradigms as reference to reach a complete and coherent framework about word recognition from a cognitive neuropsychological perspective. In sum, the converging evidence from all these techniques will be useful in understanding how words are activated, selected and finally identified in our minds, that is, in understanding the dynamics of the mental lexicon.

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