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Determining the time course of lexical frequency and age of acquisition using ERP

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ABSTRACT

Objective: The main goal of the present study was to dissociate the effects on reading of frequency, age of acquisition (AoA) and imageability using the evoked response potential paradigm.
Method: Twenty participants read words from three experimental conditions: high and low frequency, late and early age of acquisition and high and low imageability.
Results: High frequency words produced more positive mean amplitude than low frequency words in the 175–360 ms post-stimulus onset time window and late AoA produced more negative amplitudes than early AoA in the 400–610 ms window. Imageability did not produce any effect in any time window tested. Brain electromagnetic tomography showed the most activated cortical areas for each category of stimuli.
Conclusions: The lexical frequency of words seems to affect an early phase in the recognition process, perhaps at the level of the orthographic input lexicon, while AoA was observed at a later stage, indicating that this variable influence processing at a semantic level or at the links between semantics and phonology.
Significance: EEG permits the researcher to investigate the time course, and approximate location in the brain, of psycholinguistic variables.

1. Introduction

It has long been assumed that the most important determiner of visual word recognition performance is a word's frequency of use. Words that are used more often elicit shorter recognition times. For this reason, the main psycholinguistic models have tried to explain the effects of frequency on word recognition (Coltheart et al., 2001; Morton, 1979; Seidenberg and McClelland, 1989). However, recent studies have supported the view that an important part of the variance attributed to lexical frequency corresponds instead to other variables that were not previously considered; variables such as length, imageability, orthographic neighbourhood and age of acquisition (AoA). In the case of AoA, the source of the confound is the high correlation between frequency and AoA since higher frequency words are usually acquired earlier in life (Morrison and Ellis, 1995).

Many attempts have been made in the last few years to distinguish the effects of frequency and AoA in order to determine the weight and causal locus of each. Two methods have been used to do so. In one, experimenters have employed orthogonal manipulation of the variables (Gerhand and Barry, 1999), in the other, they have employed multiple regression analyses to try to distinguish the influence of each variable on reaction times recorded with presentation of large samples of words (Cuetos and Barbón, 2006; Barca et al., 2002). The results show that AoA and frequency are probably independent variables affecting different processes. Evidence for this conclusion lies in the observation that the most powerful effects of lexical frequency are seen in relation to performance in the lexical decision task, whereas the most powerful effects of AoA are observed in the picture naming task (Cuetos et al., 2006). Thus, it seems that frequency acts at a lexical level but the locus of the AoA is not clear. At least three possible loci for the effect of the latter variable have been proposed: at the level of phonological access (Gerhand and Barry, 1999); at the semantic level (Brysbaert et al., 2000); or at multiple levels, as sustained by the mapping hypothesis (Ellis and Lambon Ralph, 2000).

The use of event-related potentials (ERPs) represents an important advance on the reaction time methodology because it allows one to extract detailed information on the temporal course of cognitive processes. If two variables produce activation at different time windows, it can be inferred that they are dissociable and therefore correspond to different processes of the reading system. An examination of the latency, early or late, at which the effect on the electrophysiological brain responses is observed may advance conclusions about the prelexical, lexical or postlexical locus of

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the effect, and its orthographic, phonological or semantic nature (Dehaene, 1995; Domınguez et al., 2004; Hauk et al., 2006; Holcomb and Grainger, 2006).

There are a few examples of studies in which researchers have probed the brain responses to intercorrelated psycholinguistic variables using ERPs. Hauk and Pullvermüller (2004) reported an attempt to dissociate the effects of the frequency and length variables, which correlate because the most frequent words are usually the shortest. They conducted a lexical decision experiment and found differences in the time course of electrophysiological responses to each variable. Length variation elicited a very early effect, observed in the 80–125 ms epoch, whereas high and low frequency words differed later, at around 200 ms (the point at which lexical access is supposed to occur). Tainturier et al. (2005) administered both auditory lexical decision and semantic categorization tasks to try to distinguish brain responses to variation in frequency and AoA using ERP. Although they did not find a significant difference in the amplitudes of the P300/N400 components in responses to the semantic categorization task, they did find differences in the P300 component in responses to the lexical decision task. Earlier acquired words elicited more positive amplitudes at parietal electrodes than late acquired words. Considering that P300 could be considered a phonological marker, the authors concluded that the locus of AoA should be located at the phonological level and not at the semantic level. Frequency variation, on the other hand, did not produce significant effects. As far as we know no studies have been carried out on visual word recognition in which ERPs have been used to investigate frequency and AoA.

Converging evidence on the dissociation of AoA and frequency effects has been yielded, however, in several fMRI studies that have been conducted to try to separate the effects of these two variables. All have demonstrated that AoA and frequency affect brain activity in different areas. Fiebach et al. (2003) used the lexical decision task while registering brain activity with fMRI. Frequency was found to mainly activate the frontal inferior brain area whereas AoA had a more distributed effect with diverse areas of activation, among them, the precuneus and the temporal as well as frontal inferior lobes. Weekes et al. (2004) also obtained similar results (in Chinese) with fMRI recordings made during lexical decision. Participants in the study reported by Joubert et al. (2004) were asked to read high frequency words, low frequency words and pseudowords while brain activity was recorded with fMRI. The high frequency words produced greater activation of the left supramarginal area (associated with lexical orthographic processing) and the low frequency words and the pseudowords activated the inferior frontal area and the medial temporal area (associated with phonological processing). Also, Hernandez and Fiebach (2006) recorded brain activity during silent reading with fMRI and found that later acquired words produced more activation at the left posterior superior temporal gyrus, the right globus pallidus, the putamen and Brodmann areas 9 and 44. These authors stated that late AoA is associated with processing in areas of the left hemisphere, involved in phonological access, while the right hemisphere areas are involved in articulatory processes. They also concluded that words acquired at an early age are connected to semantic processes.

The aim of the present study was to use ERPs to investigate the effects of frequency and AoA to determine the time course of responses to variation in these factors in order to find evidence for their causal locus in relation to the reading process. Moreover, we carried out source analyses to obtain information about the brain localization of possible effects. One task that could be used to study the effects of frequency and AoA on reading is word naming (Cuetos and Barbón, 2006), however, the electrical interference associated with muscular movements occurring during reading aloud would contaminate the electrophysiological recordings, creating excessive noise in ERP signals. Lexical decision does not entail these problems but performing that task involves lexical competition and decision making processes that render uncertain the location in the reading process of any effect, that is, in terms of whether the effect can be attributed to prelexical, lexical or postlexical levels (Balota and Chumbley, 1984). Given these considerations, we decided to use the silent reading task because while the task corresponds to natural reading behaviour it should more readily afford elucidation of observed brain responses to frequency or AoA variation in the words presented to participants for reading.

The silent reading task has proved useful in the ERP investigation of the component processes of reading and available evidence indicates that phonological coding processes occur even though overt responses are not required. Niznikiewicz and Squires (1996) reported a study in which they used the silent reading task, presenting sentences in which the final words could be replaced by a homophone, an orthographically related word, a semantically related word or an unrelated word. These authors observed an increase of amplitude in the N200 component associated only with reading homophones words which suggests that even during silent reading phonological information is activated. In a similar study, Newman and Connolly (2004) also manipulated the final words of sentences presented for reading, with the critical word stimuli consisting of phonological, orthographic, and semantic relatives of the original sentence-final words but also non-words that were pseudohomophones of the sentence-final words. The results showed a clear effect of pseudohomophony on the N270 component and no effects on the N400 component. Based on their findings, these authors concluded that phonological processes occur at an earlier time in sentence reading whereas semantic processes occur at a later point.

The goal of the present work was to investigate the time course of word recognition processes using ERP recording to study the effects of key psycholinguistic variables such as frequency, AoA and imageability on the silent reading of isolated words. AoA has been shown to significantly influence reading latencies in Spanish oral reading (Alija and Cuetos, 2006; Cuetos and Barbón, 2006) even when other correlated variables are taken into account in multiple regression analyses. We also investigated the effect of lexical frequency because of the high correlation between AoA and frequency and the continuing debate concerning whether these variables have separable effects. Imageability was included to test whether semantics is involved in reading in a language with a transparent orthography.

Spanish has a transparent orthography because by using a grapheme-to-phoneme mechanism the Spanish-speaking reader can obtain the sound of words with absolute regularity. Therefore, for this type of language the semantic representation of words when reading aloud cannot be justified in the way that it is argued to be by Strain et al. (1995), in English, for words that are difficult to read because they are low frequency and have inconsistent exception pronunciations (Strain et al., 1995). Nevertheless, while imageability was found not to affect oral reading latencies in healthy adult Spanish speakers (Cuetos and Barbón, 2006), it has been shown to influence the reading accuracy of patients presenting with acquired dyslexia, at least, for longer words (Davies and Cuetos, 2005). It has been argued by Davies and Cuetos (2005) that the interaction between length and imageability is observed to affect patient reading accuracy because longer words require more time for phonological coding to be completed, affording the opportunity for semantics to influence oral reading in a manner analogous to the opportunity afforded by the difficulty imposed in English by low frequency exception words. Thus, it is possible that the effects of this variable would not be detected in overt reading reaction times in healthy adults but may instead be detected with ERPs. Moreover, we were interested in investigating whether the