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The processing of consonants and vowels during letter identity and letter position assignment in visual-word recognition: An ERP study

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ABSTRACT

Recent research suggests that there is a processing distinction between consonants and vowels in visual-word recognition. Here we conjointly examine the time course of consonants and vowels in processes of letter identity and letter position assignment. Event related potentials (ERPs) were recorded while participants read words and pseudowords in a lexical decision task. The stimuli were displayed under different conditions in a masked priming paradigm with a 50-ms SOA: (i) identity/baseline condition e.g., chocolate-CHOCOLATE); (ii) vowels-delayed condition (e.g., choc░l░te-CHOCOLATE); (iii) consonants-delayed condition (cho░o░ate-CHOCOLATE); (iv) consonants-transposed condition (cholocate-CHOCOLATE); (v) vowels-transposed condition (chocalote-CHOCOLATE), and (vi) unrelated condition (editorial-CHOCOLATE). Results showed earlier ERP effects and longer reaction times for the delayed-letter compared to the transposed-letter conditions. Furthermore, at early stages of processing, consonants may play a greater role during letter identity processing. Differences between vowels and consonants regarding letter position assignment are discussed in terms of a later phonological level involved in lexical retrieval.

1. Introduction

One of the critical sub-processes in visual-word recognition involves the mapping of an abstract letter representation onto a whole-word representation. To complete this stage in an alphabetic language, both the identity and the position of the letters have to be computed – if not, one would not be able to distinguish salt and slat, or hat and that. None of the influential computational models of visual-word recognition that employ a slot coding scheme (e.g., interactive activation model, McClelland & Rumelhart, 1981; DRC model, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; MROM model, Grainger & Jacobs, 1996; CDP + model, Perry, Ziegler, & Zorzi, 2007; Bayesian Reader model, Norris, 2006) can accommodate the presence of the effects of transposed-letter priming (e.g., *relovution* primes *RELOVUTION* more than *retosution*; e.g., Perea & Lupker, 2004) and relative position priming (*BLCN* primes *BALCON* more than *CTR;* Grainger, Granier, Farioli, van Heuven, and Van Assche, 2006; Peressotti & Grainger, 1999). This limitation has been overcome by more flexible input coding schemes (e.g., SERIOL model, Whitney, 2001; SOLAR model, Davis, 1999; open-bigram model, Grainger & van Heuven, 2003; and overlap model, Gomez, Ratcliff, & Perea, 2008). One problem here is that vast majority of implementations of these input coding schemes do not specify any processing differences as a function of the letter status (i.e., vowel vs. consonant). The exception is the current version of the SERIOL model (see Whitney & Cornelissen, 2005), in which letter encoding is parsed into a graphosyllabic representation in which vowels and consonants would have separate slots; however, no specific predictions are made in this model for the effects of manipulating consonants vs. vowels. There is growing research, however, that shows that vowels and consonants are not processed in the same way during the processing of written words (e.g., Berent & Marom, 2005; Buchwald & Rapp, 2006; Carreiras, Dunabeitia, & Molinaro, 2009; Cutler, Sebastian-Galles, Soler-Vilageliu, & van Ooijen, 2000; Lee, Rayner, & Pollatsek, 2001; Lee, Rayner, & Pollatsek, 2002; New, Araujo, & Nazzi, 2008; Perea & Lupker, 2004).

One important approach to examining the time course of processing of consonants and vowels is by measuring ERP waves in a visual-word recognition task. In a recent ERP study using a single-presentation lexical decision task, Carreiras, Vergara, and Perea (2007) obtained differences in an early time window (300–500 ms) between the processing of pseudowords created by

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replacing two letters of their base word (e.g., *retosución*; the base word was *REVOLUCIÓN*) and the processing of pseudowords created by transposing two letters (*relovución*), and this occurred for both consonant and vowel-transpositions. However, in a later time window (500–650 ms), they observed different effects for the consonants-transposed pseudowords and for the vowels-transposed pseudowords. More recently, Carreiras, Vergara, and Perea (2009) found this consonant/vowel dissociation in a masked priming experiment in which the primes were pseudowords created by the transposition/replacement of two vowels or two consonants. Finally, Carreiras, Duñabeitia, et al. (2009) showed that the status of letters (consonants vs. vowels) modulated the process of letter position assignment in relative position priming. At 175–250 ms and 350–450 ms time epochs, words preceded by relative position primes composed of consonants (*frl-FAROL*) elicited the same ERP waves as the words preceded by an identity priming condition (*farol-FAROL*), whereas words preceded by a relative position prime composed by vowels (*aeo-ACERO*) showed ERP waves similar to an unrelated priming condition (*iui-ACERO*).

Another paradigm used to analyze the different role of consonants and vowels in visual-word recognition is to delay the presentation of one/two letters (either consonants or vowels) for a short period. Lee et al. (2001, 2002) used a delayed-letter presentation paradigm where the onset of several letters (vowels or consonants) was delayed at the beginning of a word fixation during sentence reading. They showed that delaying a consonant for 30 ms increased gaze durations on the target word relative to delaying a vowel. More interesting for the present purposes, Carreiras, Gillon-Dowens, Vergara, and Perea (2009) employed a similar procedure in a lexical decision task while collecting the ERP waves. Carreiras et al. found larger N250 amplitudes for the consonants-delayed (e.g., *RE O UCION – REVOLUCION*) compared to the identity condition over all scalp areas, while the differences regarding this component between the vowels-delayed and baseline conditions were only observed in posterior scalp areas (*REV L CION – REVOLUCION*).

In addition, there is evidence that strongly suggests that there is a differential role of consonants and vowels in other areas of language processing. Several phonology-related phenomena have the effect of reducing the contrastive power of vowels (e.g., vowel harmony and centralization of unstressed vowels), and this impoverishes their role in distinguishing lexical items (Bonatti, Peña, Nespor, & Mehler, 2005). Indeed, 20-month-old infants can learn two words that differ by only one consonant, but fail when the distinctive phoneme is a vowel (Nazzi, 2005; Nazzi & New, 2007). Furthermore, humans are better at capturing non-adjacent regularities based on consonants than on vowels (Bonatti et al., 2005; Mehler, Peña, Nespor, & Bonatti, 2006). In contrast, vowels are used to extract structural generalizations in artificial languages (Nespor, Peña, & Mehler, 2003; Toro, Nespor, Mehler, & Bonatti, 2008). It has also been suggested that consonants carry lexical information while the main role of vowels is that of allowing the identification of the rhythmic class as well as of specific properties of syntactic structure (see Nespor et al., 2003, for a review). Finally, neuropsychological dissociations show that the processing of these two types of speech segments is dissociable by brain damage (see Caramazza, Chialant, Capasso, and Miceli, 2000).

If consonants are so powerful in terms of quality distinctions among lexical representations, it is important to examine the time course of consonants/vowels during the processes of letter identity and letter position assignment. Note that previous ERP studies examined either letter position processes or letter identity processes, but they have not considered all these conditions in a single experiment; obviously, the lack of a conjoint experiment to examine these issues makes it difficult to meaningfully compare the time course of letter identity/position for vowels and consonants. To this purpose, in the present experiment we will conjointly examine the role of letter identity and position – of vowels and consonants – during visual-word recognition while measuring the ERP waves. We manipulated, on the one hand, the delay of vowels and consonants (REVOLUCION was preceded by either *re-v░l░cion* or *re░o░ucion*) and, on the other hand, the transposition of vowels vs. consonants (REVOLUCION was preceded by either *revulocion* or *relovucion*).

One novel manipulation was the inclusion of a baseline condition (identity condition). In previous studies (Carreiras et al., 2007; Perea & Lupker, 2004), the control condition was a prime created by substituting the letters (e.g., the orthographic control for *relovución* was *retosución*). In order to measure independent effects for the identity and the position of the letters, a more appropriate baseline should be an identity prime, as it provides an index of how similar the pseudoword prime is to the "best" condition (i.e., the identity condition; see also Carreiras, Gillon-Dowens, et al., 2009).

In sum, we will compare the time course of delayed/transposed-letter effects, regarding the different role of vowels and consonants during visual-word recognition. ERPs provide decomposable measures of online processing and enable fine-grained descriptions of processing due to the excellent time resolution of this technique. ERPs are voltage changes recorded from the scalp and extracted from the background electroencephalogram by averaging time-locked responses to stimuli onset. Of specific interest for our study are the following components: N250 and N400. The N250 component has been associated with the degree of prime-target orthographic overlap and phonological overlap in masked priming, suggesting that it is sensitive to processing sub-lexical representations (Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006). Furthermore, Carreiras, Gillon-Dowens, et al. (2009) obtained larger N250 amplitudes for the consonants-delayed condition than for the baseline condition using this ERP component.

The N400 component is a negative deflection occurring around 400 ms after word presentation that has been associated with lexical-semantic processing (see Holcomb, Grainger, & O'Rourke, 2002; Kutas & Federmeier, 2000). The amplitude of this negativity is an inverse function of lexical frequency and lexicality (Carreiras, Vergara, & Barber, 2005; Neville, Mills, & Lawson, 1992; see also Barber & Kutas, 2007, for a review). In addition, items from small orthographic/syllabic neighborhoods produce an N400 of smaller amplitude than items from a large orthographic/syllabic neighborhood (Barber, Vergara, & Carreiras, 2004; Holcomb, Grainger, & O'Rourke, 2002). Larger neighborhoods produce higher levels of activation, either at the level of form representation or at the level of semantic representation (Holcomb, Grainger, & O'Rourke, 2002). Carreiras et al. (2007) showed that transposed-letter consonant pseudowords produced a modulation of the amplitude in a late time window (500–650 ms) in the same way as orthographic neighborhoods do. Carreiras et al. concluded that transposed letter-pseudowords created by transposing two consonants activated their corresponding base word to a larger degree than the transposed letter-pseudowords created by transposing two vowels.

If the contribution of consonants and vowels to the letter assignment process is different and has a different time course, we expect our manipulations to have a differential impact on the ERP components described above. Previous research has shown early differences between both vowels- and consonants-delayed conditions, and the identity condition (Carreiras, Gillon-Dowens, et al., 2009), while in another study, Carreiras et al. (2007) found that transposed-letter effects show up later in time relative to a replacement letter condition (Carreiras et al., 2007). If consonants act as "islands of reliability" regarding orthographic processing – and also operate as the basic skeleton of lexical representations, we should expect early differences for consonant and vowel