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Letter coding in visual word recognition: The impact of embedded words

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ABSTRACT

Nonword classification responses are examined in this study to establish the amount of interference arising from the presence of an embedded word. In Experiment 1, greater interference is found from an initial embedding (e.g., *furb* vs *lurb*, cf. *fur*) than a final embedding (e.g., *clid* vs *clig*, cf. *lid*). In addition, an "outer" embedding (e.g., *jomb* vs *vomb*, cf. *job*) generates interference that is no greater than for an initial embedding. These results are inconsistent with the idea of left-to-right parsing, while accounts of word recognition that center on open bigrams or the spatial coding of letters require additional processes. Instead, the results are interpreted within a model of word parsing and lexical access that incorporates subsyllabic structures; an account that is supported in Experiments 2 and 3 by the critical finding that an initially embedded word interferes more when it ends in a consonant (e.g., the *fur* of *furb*, the *shadow* of *shadowl*) than with a vowel (e.g., the *tea* of *teaf*, the *coffee* of *coffeep*).

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Introduction

As with most of the world's alphabetic scripts, English is read from left to right. Not only are the words in a sentence ordered in that direction, but the letters within each word correspond to each sound of the word in a left-to-right manner. This fact about the language might therefore be taken to mean that visually presented English words are recognized via a parsing mechanism that matches the individual letters to a stored lexical representation by starting from the left of the word and proceeding in a rightward direction. Such a left-to-right parsing mechanism was indeed proposed by Taft (1979) whereby a word was said to be recognized when larger and larger units were compared to representations stored in the mental lexicon until a match was made. For example, the word *climb* would be recognized after trying to access *cl*, *cli*, *clim*, and ultimately *climb* in lexical memory. A left-to-right processing model was also proposed by Kwantes and Mewhort (1999) where words are processed sequentially from their initial letter until there are no possible candidates remaining (though see Miller, Juhasz, and Rayner (2006), for evidence against this).

Support for left-to-right parsing would be seen if the correct classification of a letter-string as a nonword (i.e., a lexical decision response) were delayed by the presence of an initially embedded word, but not a finally embedded one. For example, the lexical representation for *meat* would be activated during the processing of the item *meath*,[1] but not during the processing of *smeat*, hence making it easier to decide that the latter is not actually a word. Such a result was reported by Taft (1979), along with the equivalent finding for real word items that had a competing

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[1] Underlining will be used to indicate the word embedded in a stimulus item. However, no underlining was actually present in the experiment.

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word embedded within them (e.g., a delay in recognizing *beard*, but no delay in recognizing *clove*). Interference to the lexical decision response was measured against a matched control item that had no embedding (e.g., *houth* in comparison to *meath*, or *storm* in comparison to *beard*). While the results of this study are entirely in line with a strictly left-to-right parsing mechanism, there is a potential problem with the experimental materials that were used inasmuch as the nonword control items were matched to their embedded pairings only in terms of having "similar orthographic structure" (Taft, 1979, p. 33). Such a basis for matching is so imprecise that it is quite possible that general likeness to a real word was poorly controlled. For example, the embedded and control items may not have been adequately matched on the number of words from which they differed by one-substituted letter (i.e., neighborhood size or "*N*"), which is a factor that has been shown to be important in word recognition (e.g., Andrews, 1989, 1992; Coltheart, Davelaar, Jonasson, & Besner, 1977). Similarly, the word items were only matched with their controls on word frequency, hence ignoring how confusable they were with other words.

In fact, the idea of left-to-right parsing might be seen as being incompatible with a well-established finding in another domain of visual word recognition. In particular, a word is less strongly activated when its final letters are transposed (e.g., *clibm*) than when its internal letters are transposed (e.g., *clmib*). Such a positional effect on transposed letter (TL) processing has been shown in the masked priming paradigm (e.g., Perea & Lupker, 2003a, 2003b; Schoonbaert & Grainger, 2004, at least for 5 letter words), in lexical decision responses to nonwords (e.g., Chambers, 1979), and in eye tracking research (e.g., Johnson & Eisler, 2012; White, Johnson, Liversedge, & Rayner, 2008), and might be seen as contradictory to the left-to-right parsing model. This is because information about the final letter appears to take priority in processing over letters that occur earlier in the word (apart from the initial letter, whose disruption was also shown to reduce the impact of transposed letters in the above studies). However, such a situation does not have to mean that final letters are processed earlier than medial letters. It might simply mean that the units fed into a left-to-right parsing system are imprecisely coded in relation to the medial letters such that, for example, even when *clmib* is presented, an attempt is made to access *cli*, *clim*, and *climb*. In contrast, the space after the final letter prevents lateral inhibition and therefore leads to greater precision in coding (see e.g., Johnson & Eisler, 2012; Whitney, 2001) which means that *climb* is not a candidate unit when *clibm* is presented (unlike *clb*, *clib*, *cil*, and *cilb*).

There have been several other more recent studies, however, that appear to show that a finally embedded word might have an impact on the identification of a letter-string in contradiction to the findings of Taft (1979) and, hence, to the idea of left-to-right parsing. In the first of these studies, Davis and Taft (2005) observed interference to nonword classification responses when there was a word embedded in final position. Unlike the study of Taft (1979), the nonwords that had a final embedding were carefully matched to their controls, not only on *N*, but also on other potentially important word-likeness factors such as mean bigram frequency, and the frequency of their subsyllabic "onset" and "body". The onset of a syllable comprises any consonants that precede the vowel, while the consonants that follow the vowel constitute the coda which, in combination with the vowel, forms the body of the syllable (e.g., *climb* has the onset *cl* and the body *imb*, which in turn comprises the vowel *i* and coda *mb*). Body and onset frequency were carefully controlled in the Davis and Taft (2005) study by re-combining the same onsets and bodies to create the embedded nonwords (e.g., *dwish*, *clift*) and their matched controls (*clish*, *dwift*).

An examination of the materials used in that experiment, however, reveals that a number of the finally embedded items (and none of the control items) also had what can be called, an "outer embedding". For example, the letter-string *dwish* not only includes the finally embedded word *wish*, but its outer letters also form the word *dish*. It is therefore possible that the interference effect observed by Davis and Taft (2005) with nonwords was driven to at least some extent by the existence of a word containing all but one medial letter of the nonword, rather than by the word embedded at the end. Such a possibility is reinforced by a further experiment reported by Davis and Taft (2005) which showed interference on lexical decision responses to word items not only when they had a higher frequency word embedded in initial position (e.g., *drawl*, *closet*), but also when they had an outer embedding (e.g., *rinse*, *sturdy*). Interference appeared to be weakest when the embedded word was in final position (e.g., *brisk*, *trifle*), but the interaction with position failed to reach significance on the analysis of item means.

It is important to note that even if an embedded word were to be activated more strongly when in outer position than in final position, it would still be inconsistent with a strict left-to-right parsing mechanism. At no point in the left-to-right processing of *dwish*, for example, would the lexical representation for *dish* (or *wish*) become a candidate for recognition.

In the only other reported lexical decision experiment looking at the impact of embedded words, Davis, Perea, and Acha (2009) examined Spanish polysyllabic items and concluded, in contrast to Davis and Taft (2005), that finally embedded words had no impact on either word or nonword classification responses, unlike initial and outer embeddings. However, despite the claimed lack of interference for the finally embedded items, the interaction between interference and position of embedding failed to reach significance in the item analysis of either the speed or accuracy measure for both the word and nonword items. Moreover, the interference on error rates for nonword items was larger, if anything, when the embedded word was in final position than in the initial or outer positions. Therefore the data presented by Davis et al. (2009) are equivocal with regard to the impact of finally embedded words, despite the authors' conclusion that no impact was observed.

Another way in which embedded words have been examined is within a category judgement task. Bowers,

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