COMPETITOR EFFECTS IN AUDITORY WORD RECOGNITION: IMPLICATIONS FOR INTERACTIVE-ACTIVATION MODELS OF WORD RECOGNITION

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ABSTRACT

The TRACE model of word recognition predicts the activation of "words within words" (tar in guitar). Simulations with TRACE are reported which demonstrate that the level of this activation is affected both by the size of the set of competing word hypotheses (a "prefixing effect") and by the presence of a high-frequency competitor. A cross-modal priming study is described which supports and extends these predictions.

INTRODUCTION: THE TRACE MODEL

TRACE [1] is currently the most computationally explicit model of word recognition. It has an interactive-activation architecture with three different levels of representation — features, phonemes and words; the parameters governing the interactions within and between these levels may be independently manipulated. The very existence of these different types of interaction in the human speech processing mechanism (HSPM) is a fundamental theoretical issue. TRACE's authors claim empirical support for these interactions from perceptual studies. When TRACE receives an input, numerous lexical hypotheses are activated, which then compete with each other until one predominates. TRACE makes a number of predictions about this competition which have testable perceptual implications. In this paper, TRACE's basic mechanism is described, then a number of predictions are demonstrated, and finally a cross-modal priming study [2], measuring transient word-activations, is described which offers experimental support for TRACE's behaviour.

Input to TRACE consists of a sequence of feature-level descriptions made available across a number of discrete time-slices. TRACE's architecture is localist: an individual node stands for a specific feature, phoneme or word at a specific point in time. There are separate nodes representing the phoneme /g/ at the point in time monitored by that node. There is intra-level inhibition, and inter-level activation: activated nodes within any level compete to suppress each other, while mutually consistent nodes in adjacent levels reinforce each other's activation level.

As the feature-level nodes become activated by the input, they activate the relevant phoneme-level nodes, which in turn generate activation at the word-level. Activation of nodes within a level allows competition to occur within that level. Activation at the word level allows the top-down activation of consistent nodes at the phoneme level. A complex pattern of activation results, reflecting TRACE's ability to allow all of the words in its lexicon to compete at each point in time to the extent that they are activated by the input. TRACE's output is an activation level for each node for each point in time. Plotting these levels against time produces the activation curve for a particular lexical or phonemic hypothesis. The actual recognition of a word is an independent issue which may be modelled by a decision rule which compares the relative activations of the word nodes.

PREDICTIONS FROM TRACE

TRACE makes the following predictions.

(i) A sequence of segments which is homophonic with a monosyllable, but which is embedded within a longer word will, in principle, be able to activate the representation of that monosyllable.

That is, the second syllable of the input guitar should cause the activation of tar. (Henceforth, "the activation of x" will be used to mean "the activation of the node representing x"). Figure 1 shows the activation curve for guitar when the input is a feature-level description of that word; there is also a brief activation of tar caused by the latter half of the input. This happens because segmentation in TRACE does not occur prior to lexical access/activation. All activated words compete, even though they may only partially overlap with the input.
Fig. 1. Activation of *guitar* and *tar* when the input is *guitar*.

Fig. 2. Activation of *guitar* and *tar* for unique lexicon (curves a and z), for *gi*-prefixed lexicon (curve b; no activation of *tar*), and for the *git*-prefixed lexicon (curves c and z). Input is *guitar*.

Fig. 3. Activation of *guitar* and *tar* for unique lexicon (curves a and z), for *gi*-prefixed lexicon (curves b and y), and for the *git*-prefixed lexicon (curves c and z). Word-to-phoneme activation turned off in each case; input is *guitar*.

Fig. 4. Activation of the /t/ and /a/ nodes for unique lexicon (curves a and z) and for *gi*-prefixed lexicon (curves b and y). Curve c is the curve for /t/ for the *git*-prefixed lexicon. Word-to-phoneme activation turned on in each case; input is *guitar*.

Fig. 5. Activation of *guitar* and *tar* for the unique lexicon (curves a) and for lexicons which contain increasing numbers of *gi*-prefixed words; in the last case, the curve for *tar* is a single point. Input is *guitar*.

Fig. 6. Activation of *guitar* and *tar* (curves a and b) when the lexicon also contains a high-frequency *gi*-prefixed competitor (curve c); the solid lines are activation curves with the effects of frequency were turned off, for comparison. Input is *guitar*.
and with each other; segmentation falls out of recognition. Frauenfelder and Peeters [3] argue that although prediction (i) is true in principle, TRACE's architecture ensures that the activation advantage which the "carrier word" (guitar) has over the word-final "embedded word" (tar), by virtue of the processing of the first syllable of the carrier word, causes the effective suppression of the embedded word. In Figure 1, the activation level of the embedded word is only a fraction of that of the carrier word.

(ii) If the first syllable of the carrier word behaves like a prefix, activating a substantial number of words which all begin with that syllable but which then disagree in the first segment of the embedded word, then the embedded word will be suppressed. That is, TRACE predicts a prefixing effect even though prefixed words and morphemic words are both stored as simple, whole words. In Figure 2, "a" is the activation curve of guitar in the "unique" lexicon, in which guitar is the only word beginning g i-; "x" is the corresponding activation of tar. Curve "b" is the curve for guitar in the "gi-prefix" lexicon, which contains a group of "prefix" words all starting with the artificial prefix gi-, but then differing on the third segment. These competing hypotheses ensure that guitar rises more slowly to its asymptotic value, but, crucially, there is no activation at all of tar in this prefixed case. Finally, "c" is the curve for guitar in the "git-prefix" lexicon, in which the competing words do not disagree on the third segment but all contain /t/ at that point; that is, the prefix git- overlaps with the embedded word. This suppresses the early activation of guitar even more than before, but also causes the activation curve of tar to rise substantially above the "unique" condition.

This latter increased activation of the embedded word demonstrates what Frauenfelder and Peeters claim is a general rule governing the activation of embedded words by TRACE: the carrier word is the main inhibitor of an embedded word and therefore any lexical competition which inhibits the carrier word indirectly increases the activation of the embedded word. The prefixing effect demonstrated above is a departure from this general rule and arises because TRACE's architecture allows an activated word node to increase the activation of its constituent phonemes, top-down. If the first syllable of guitar also activated giddy, then giddy would reinforce the activation level of /d/ at the phoneme level, which would in turn compete with /t/ at that level. Inhibiting /t/ in turn decreases the activation of tar at the word-level.

Sufficient inhibition of /t/, as in the prefixing case when a substantial number of highly activated word hypotheses disagree on the first segment following the prefix, can completely suppress the embedded word. In simulations in which word- to phoneme-level activation is turned off, the prefixing effect disappears and the activation curves for guitar and tar in the gi-prefix lexicon are both intermediate between those for the unique lexicon and the git-prefix lexicon (see Figure 3). Figure 4 shows the corresponding activation of the /t/ and /a/ nodes in these simulations; the /t/ node is more affected — its position is crucial.

(iii) When a word-final embedded word is suppressed by the word-initial cohort generated by the carrier word, the activation of the embedded word should vary inversely with the number of words in the word-initial cohort. In Figure 5, the two series of curves represent the activation of guitar and tar respectively, in part of a series of simulations with different lexicons in which the number of words beginning with gi- is successively increased. The largest curve for tar is in the unique lexicon; the other curves reveal successively less activation. This occurs because the activation from guitar's lexical competitors to their constituent phonemes is summed, so that, although there is competition between these competitors, the more words in the carrier word's word-initial cohort, the more competition there will be at the phoneme-level with the first segment of the embedded word.

(iv) A high-frequency competitor activated by the first syllable of the carrier word suppresses the activation of an embedded word.

This is a further departure from the general rule, in that a competitor suppresses both the carrier word and the embedded word. Figure 6 shows the activation of a high-frequency gi- competitor (curve "c") by the first syllable of guitar. Word frequency differences are realised in TRACE by adding a function of log frequencies to the resting level of the word nodes. When the feature-level description corresponding to the /t/ in guitar arrives, although this disconfirms the competing hypothesis, that hypothesis is still activated to a considerable degree even though its activation level is falling, meaning that both guitar and tar are inhibited by competition within the word-level.

In TRACE, the activation of an embedded word will be determined by some combination of the number of words
activated, their level of bottom-up activation, their frequencies, their mutual inhibition, and the consequences of their effects on the phoneme-level. Despite quantitative variation in TRACE's behaviour, caused by different parameter settings and different composition of the lexicon, certain qualitative behaviours emerge which make predictions about the HSPM. Central to these is that the process of recognizing a word is influenced by its competitors during the processing of that word, rather than at some later stage.

EXPERIMENT

A cross-modal priming experiment was performed using 48 sentences like (1).

(1) I carefully placed the trombone on the table.

The critical word, trombone, contains a lexically stressed second syllable which constitutes an embedded word, bone. Subjects heard the sentence over headphones and, at the acoustic offset of the embedded word, saw a letter-string on a screen and made a timed visual lexicon decision. The letter-string was either related to the embedded word (rib) or an unrelated control word (bus). In two different conditions, a version of the sentence was presented in which the embedded word (bone) appeared as the critical word. Full experimental details are given in [2]. Facilitation of the response to the related word (rib) indicated activation of the embedded word (bone).

Prediction (i) was supported: for the 24 monomorphemic words (trombone, cadet...), the embedded word produced a mean level of priming of 33 msec ($F(1,23) = 9.04, p < .01; F(2,1,123) = 5.30, p < .05$). Recognition of rib was facilitated equally by trombone and bone.

Prediction (ii) was supported: no priming was found in the case of the 24 prefixed words (report, defence...). While port primed wine, report did not.

Prediction 3 was not supported. There was no significant correlation between priming and the number of words in a dictionary-calculation of the carrier word's word-initial cohort. (This agrees with the results of a further cross-modal priming experiment [4].) TRACE indicated the importance of the first segment of the embedded word (Figure 4) and the data revealed, in fact, a significant correlation between priming and the degree of divergence at that point in the cohort (how many different segments could follow the first syllable), $r = -.310, df = 46, p < .025$: the greater the range of phonemes which receive lexical support to compete with the first phoneme of the embedded word, then the less the activation of that word. Lexical statistics were calculated from the 22,350 phonemically transcribed words in the MRC Psycholinguistic Database [5] which also appear in Francis and Kucera [6].

Prediction (iv) was supported. Priming was negatively correlated with the frequency of the most frequent word in the word-initial cohort (give in guitar's cohort): for all stimulus materials $r = -.291, df = 46, p < .025$; for the monomorphemic words, $r = -.379, df = 22, p < .05$; there was no significant correlation for the prefixed words alone, $r = -.072, df = 22$, n.s.

DISCUSSION

Many of TRACE's predictions about the HSPM are supported by data on the transient activation of embedded-word hypotheses. The existence of such activations has implications for segmentation strategies. The data suggest that embedded-word activations are jointly determined by the highest-frequency word-initial competitor and the whole of the competing cohort insofar as that cohort makes top-down predictions about the initial segment of the embedded word. As in TRACE, this lexical effect is seen as occurring during the process of word recognition, rather than being a post-lexical effect.

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REFERENCES