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## LEXICAL INHIBITION IN SPOKEN WORD RECOGNITION

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### ABSTRACT

Recent evidence suggests that the relations between lexical items influence the ease with which words can be discriminated and subsequently be recognized. Lexical items may influence each other via lateral inhibition during the activation process of lexical candidates [1] or via competition from neighbours at a decision stage [2]. The present study tried to distinguish between these alternatives by employing a cross-modal repetition priming paradigm. The results show that the number of competitors had an effect on low-, but not on high-frequency targets. This result is congruent with a lateral inhibition account and it underscores the relevance of lateral inhibition as a mechanism for continuous speech segmentation.

### 1. INTRODUCTION

The beginning of a word in an utterance is seldom reliably marked. This absence of a cue about where to start a lexical access attempt poses problems for current models on spoken word recognition. One possible solution to this so-called segmentation problem is an inter-word competition process as in TRACE [2] or SHORTLIST [3]. In TRACE, segmentation is accomplished via lateral inhibition between words. Word nodes are primarily activated via bottom-up information. When words are sufficiently activated, they *directly* inhibit the activation levels of other words in proportion to their own activation and the amount of phonetic overlap they share with other words. The outcome of this competition is that each phoneme in the input is assigned to a single word in the lexicon and - when words are embedded in other words (e.g., *seed* in *succeed*) - that only the single best lexical candidate

survives the competition process. Empirical evidence in favour of lexical competition has recently been obtained by [4] and [5]. However, as was noted in [6], the locus of the empirically observed competition effect may also reside in a decision stage as is for instance the case in the Neighbourhood Activation Model (NAM) [1]. In NAM competition is *indirect* in the sense that competition does not arise at the activation level of the word itself, but rather in a subsequent decision stage. Words in NAM are recognized if the ratio of the frequency-weighted input of a target word to its competitors is sufficiently high. If many competitors are activated, the ratio is lowered because the denominator is larger. In a formula, this is:

$$p(\text{ident}_{\text{target}}) = \frac{\text{input}_{\text{target}} \times \text{freq}_{\text{target}}}{\text{input}_{\text{target}} \times \text{freq}_{\text{target}} + \sum_{j=1}^n \text{input}_{\text{comp}_j} \times \text{freq}_{\text{co}}}$$

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At this stage, it has only been shown that competitors may have an influence on the recognition of a target word, but it is unclear where the origin of the competition effect resides. This may be either at the activation level of the target word itself or in a subsequent decision stage.

One way to investigate this distinction is related to the frequency of the target word. Direct competition predicts that competition effects will be smaller in high-frequency (HF) targets, because HF-targets are more potent to inhibit their competitors (see [7]). HF-targets should thus suffer *less* from competitors because they inhibit their competitors more strongly than LF-targets. In contrast, according to the indirect view, HF-targets should suffer *more* from competitors than LF-targets. This can be seen in the following example: Suppose

an HF-target has a frequency-weighted input of .6 and whose competitors have a summed frequency-weighted input of either .5 (few competitors) or 1.0 (many competitors). From the previously mentioned formula it follows that the identification ratio's of the HF-target are  $.6 / (.6 + .5) = .54$  for few competitors and  $(.6 / .6 + 1.0) = .375$  for many competitors. The competition effect for the HF-target is thus  $.54 - .375 = .165$ . Now take a LF-target with the same competitors, but whose frequency is twice as low as that of the HF-target: Its frequency weighted input is .3 and the identification ratio's are  $.3 / (.3 + .5) = .375$  for few competitors and  $.3 / (.3 + 1.0) = .23$  for many competitors. The competition effect for the LF-target is thus only  $.375 - .23 = .145$ , which is *less* than that of the HF-target. According to the *indirect* view, then, competition effects should thus be larger in HF-targets, whereas the opposite is predicted by the *direct* notion.

The present study was set up to disentangle the direct from the indirect notion on competition effects. Using a cross-modal repetition priming paradigm, visually presented HF-targets (e.g., MELK, 'milk') and LF-targets (e.g., KELK, 'chalice') were preceded by an auditory prime 'melk' or 'kelk'. This target was embedded in the bisyllabic pseudoword such that it had (a) none, (b) few, or (c) many competitors. For the targets given above, the auditory primes were *melkem* or *kelkem* (no competitors), *melkeum* or *kelkeum* (few competitors), and *melkaam* or *kelkaam* (many competitors). The competitors were determined by examining the number of words that start with *kem*, *keum*, and *kaam* (i.e., the cohort size of the second syllable). In Dutch, there are no words that start with *ke(m)*, few words start with *keu(m)*, and many words start with *kaa(m)*. Note that all competitors compete for the final 'k' in the target word. We expected to replicate, as in [4], that primes with no competitors would produce larger facilitatory effects than primes with few competitors, and that primes with few competitors would produce larger facilitatory effects than primes with many competitors. This difference in priming is referred to as the competition effect. If competition is *direct*, competition effects in LF-

targets should be larger than those in HF-targets, whereas if competition is *indirect*, they should be larger in HF-targets.

## 2. METHOD

**Subjects:** Eighty-four subjects participated in the experiment.

**Material:** Seventy-two monosyllabic CVCC words were chosen, 36 were high-frequency (HF) words (mean frequency of occurrence in the CELEX count 230.9) and 36 were low-frequency (LF) words (mean frequency of occurrence is 8.47). The words formed pairs as *melk* and *kelk* such that both had the same rime (*elk*). All words were made into bisyllabic pseudowords by the addition of an extra syllable. Three alternative endings were constructed. For the examples given above, the endings were *em*, *eum*, and *aam*, making *melkem*, *melkeum*, *melkaam*, and *kelkem*, *kelkeum*, *kelkaam* for the none, few, and many competitor conditions, respectively. There are thus no words in the Dutch CELEX lexicon that start with *ke* or *kem*, there are a few words start with *keu* or *keum*, (i.e., 83.8 and 2.1 for CV and CVC onset, respectively) and there are many words that start with *kaa* or *kaam* (631.1 and 83.9 for CV and CVC onset, respectively). Note that the number of competitors is equal for HF- and LF-targets as their endings were matched. A control condition was included in which case the prime was unrelated to the target.

The acoustic offset of each of the embedded words (for instance, at the /k/ in *melkem* or *kelkem*) served as reference for the inter-stimulus interval (ISI). The ISI was set at 250 msec so that at approximately the end of the second syllable a visual target (i.e., MELK or KELK) appeared on a CRT screen.

**Design and Procedure:** Four different versions were made, such that each visual target and each auditory prime appeared only once in the experiment. There were an additional 144 bisyllabic filler items that were the same in all four versions. Half of the visual targets were nonwords ('no' decision) and half were real Dutch words ('yes' decision). Subjects were asked to make a speeded lexical decision to the visual target by pressing a 'yes' or 'no' key.

**Table 1: Mean Reaction Times and Priming Effects for High and Low-Frequency Targets**

	<i>Spoken prime</i>	<i>Visual target</i>	<i>RT</i>	<i>Priming</i>
<b>High-frequency targets</b>				
Control	<i>hompem</i>	MELK	541	
No competitors	<i>melkem</i>	MELK	503	38
Few competitors	<i>melkeum</i>	MELK	511	30
Many competitors	<i>melkaam</i>	MELK	505	36
<b>Low-frequency targets</b>				
Control	<i>hompem</i>	KELK	620	
No competitors	<i>kelkem</i>	KELK	565	55
Few competitors	<i>kelkeum</i>	KELK	567	53
Many competitors	<i>kelkaam</i>	KELK	583	37**

### 3. RESULTS

The reaction times and priming effects (table 1) were exactly as predicted by the *direct* notion of lexical competition: Priming effects of LF-targets, but not those of HF-targets, were proportionate to the number of competitors. Facilitation was largest for LF-targets with no competitors, somewhat smaller for LF-targets with few competitors, and smallest for LF-targets with many competitors. Priming effects of HF-targets were essentially the same. A 2 (target type) x 4 (prime type) ANOVA on the reaction times showed that HF-targets were responded to faster than LF-targets [ $F_1(1,83) = 471.47, p < .001; F_2(1,32) = 38.67, p < .001$ ]. The effect of a prime was significant [ $F_1(3,249) = 46.13, p < .001; F_2(3,96) = 28.89, p < .001$ ], as was the interaction between target type and prime [ $F_1(3,249) = 4.07, p < .008; F_2(3,96) = 3.75, p < .013$ ]. To investigate whether priming effects were different, ANOVAs were performed on the amount of priming by subtracting the reaction time of the target-embedded primes from the appropriate control condition. A 2 (target type) x 3

(context) ANOVA showed that the overall difference between HF- and LF-targets was marginally significant [ $F_1(1,83) = 3.66, p = .06; F_2(1,32) = 3.29, p = .08$ ]. There was a significant overall effect of context in the subject-analysis [ $F_1(2,166) = 3.13, p < .05$ ], but not in the item-analysis [ $F_2(2,64) = 2.21, p = .12$ ]. The important interaction between target type and context was significant [ $F_1(2,166) = 4.34, p < .015; F_2(2,64) = 3.95, p < .024$ ]. Separate ANOVAs for HF- and LF-targets showed that priming of HF-targets was not different for the three types of context [ $F_1(2,166) = 1.26, p = .28; F_2 < 1$ ] whereas priming effects of LF-targets were different [ $F_1(2,166) = 5.50, p < .005; F_2(2,64) = 4.58, p < .02$ ]. Planned comparisons showed that there was no differences between HF-targets. However, LF-targets, with no competitors were faster than those with many competitors by 18 msec [ $F_1(1,83) = 1.83, p < .005; F_2(1,32) = 1.61, p < .02$ ]; there was no difference between LF-targets with no versus few competitors; and LF-targets with few competitors were faster than those with many competitors by 16 msec [ $F_1(1,83) = 1.69, p < .005; F_2(1,32) = 1.52, p < .03$ ].

#### 4. CONCLUSION

The focus of the present study was whether lexical competition effects reflect lateral inhibition of competing candidates (direct competition) or whether competition emerges at a decision stage (indirect competition). According to the direct notion, high-frequency (HF) targets should suffer less from competitors than low frequency (LF) targets, whereas the indirect notion predicts the reverse. In support of the *direct* notion, the results showed that priming effects of LF-targets - but not those of HF-targets - were proportionate to the cohort sizes of the competitors. LF-targets with many competitors (*kelkaam*) were less facilitated than LF-targets with few (*kelkeum*) or no (*kelkem*) competitors. Priming effects of HF-targets were not influenced by the number of competitors. These results are exactly as predicted by the direct notion and they thus strongly suggest that the locus of competition effects is at the activation level of the word.

These results are the first to show clearly that lexical inhibition plays an important role in spoken word recognition. The primary function of lexical inhibition may be the segmentation of an utterance into word-like units. As has been shown in several simulations [2 and 3], lexical inhibition can dissolve lexical embeddings such as the word 'car' that is embedded in 'carpenter'. Such ambiguities are extremely common in many languages [9], and lexical inhibition may be the key as to how the listeners deals with such ambiguities.

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