

VOWELS, CONSONANTS AND LEXICAL ACTIVATION

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ABSTRACT

Two lexical decision studies examined the effects of single-phoneme mismatches on lexical activation in spoken-word recognition. One study was carried out in English, and involved spoken primes and visually presented lexical decision targets. The other study was carried out in Dutch, and primes and targets were both presented auditorily. Facilitation was found only for spoken targets preceded immediately by spoken primes; no facilitation occurred when targets were presented visually, or when intervening input occurred between prime and target. The effects of vowel mismatches and consonant mismatches were equivalent.

1. INTRODUCTION

Current models of spoken-word recognition propose that speech input activates multiple candidate words which (to a greater or lesser degree) match the incoming signal, and that a process of competition between the activated words results in a single candidate eventually being recognised. Abundant experimental evidence exists to support multiple concurrent activation of word candidates [1,2,3,4,5] as well as inter-word competition [6,7,8], and both notions feature in some form in all the leading models in the current literature: Shortlist [9], TRACE [10], the Neighborhood Activation Model [11] and the latest Cohort Model [12].

In principle, it is in the interests of listening efficiency that unnecessary competition be avoided, and this can be achieved if mismatch in the input acts quickly to rule out potential competitors, leaving only forms which are fully matched by the input as active candidates. However, speech signals are often presented against competing background noise, and can often issue from unfamiliar vocal tracts manifesting acoustic features with which listeners have had no previous experience. These effects, and others, conspire to produce uncertainty about the exact nature of the input, and in such circumstances it may be to the listener's advantage if small mismatches between input and stored forms do not definitively rule out words as potential competitors. In other words, there is potential tension between the advantages and disadvantages of small discrepancies between input and lexical representation.

Considerable research attention has thus been devoted in recent years to examining exactly how degrees of match versus mismatch between input and stored representations influence lexical activation. Investigations of phonological priming have shown that lexical representations can be activated by input which almost but not quite matches their form - for instance, by words which end in the same way [13,14]. There is also evidence that spoken words can at least partially activate other words made up of similar-sounding phonemes [1,8]. These studies have not examined whether some types of match or mismatch are more effective than others. Studies using the word reconstruction task [15], however, have suggested that vowels provide

looser constraints on word recognition than consonants: vowels do not rule out other vowels as effectively as consonants rule out other consonants. In this task, listeners hear nonwords and are asked to turn them into real words by replacing a single phoneme; in English [15] and in Dutch [16] listeners find it easier to replace a vowel than a consonant. Thus the input *kebra* could become *cobra* if the first vowel is altered, *zebra* if the first consonant is altered; listeners find the vowel change easier to make than the consonant change.

Word reconstruction is not, however, a task that taps directly into the lexical activation process. Activation is more commonly assessed via lexical decision tasks, usually involving some form of priming manipulation. That is, listeners' reaction time (RT) to decide whether or not a given input sequence is a real word is measured, as a function of the presence or not of preceding input which could lead to activation of the same word.

In the present study we report two experiments of this general kind, using two different variants of the lexical decision task with slightly mismatching spoken primes. Lexical decision responses are known to be faster upon second presentation of a stimulus item [17], therefore we assume that if slightly mismatching input activates the stored representation of a word, RT to a subsequent presentation of that word will be facilitated. In both studies (one in English, one in Dutch), we address the question of whether vowels and consonants differ in the degree of match versus mismatch which they represent for the activation process.

Specifically, in each experiment we compare activation of words preceded by input mismatching only on a single vowel, only on a single consonant, or on many phonemes at once. Both English and Dutch have relatively large phoneme repertoires, which include many vowels; English in the variety here tested has 20 vowels and 24 consonants [18], Dutch 16 vowels and 19 consonants [19].

2. EXPERIMENT 1

2.1 Materials

For use as primes in the experiment, 80 nonwords (e.g. *cummel*) were constructed which mismatched two existing English words by a single vowel and a single consonant respectively (*camel*, *cuddle*). For half of the nonwords, the word mismatching on a vowel (here, *camel*) was of higher frequency of occurrence than the word mismatching on a consonant (*cuddle*), in the other half (e.g. *sarrow*: *sorrow*, *narrow*) the word mismatching on a consonant was of higher frequency. Within each such frequency set, in half of the nonwords the vowel to be changed to produce a word preceded the consonant to be changed (as is the case in *cummel*), while in the other half the reverse was the case (e.g. in *sarrow*). The full experimental prime-target sets may be obtained from the authors. A further 240 filler pairs were chosen; these included word-word pairs, which could be identical (e.g. *relent-relent*), phonologically similar (e.g. *sister-mister*) or dissimilar

(e.g. *charter-pencil*), nonword-nonword pairs (*exip-exip*, *suppre-supprose*, *snirit-dacter*) and word-nonword pairs (*saddle-seddle*, *blizzard-natten*). All 80 nonwords and 240 filler primes were recorded by a male native speaker of Southern British English.

Four presentation orders were constructed for the visual lexical decision targets, each order containing all 240 filler pairs and one version of each of the 80 experimental pairs. Each of the experimental nonword primes was matched with another (from the same frequency set, but with order of occurrence of vowel and consonant change reversed). Thus *cummel* was paired with *chorry* (*cherry*, *lorry*), and *sarrow* was paired with *timper* (*temper*, *timber*). The nonword prime *cummel* was followed by the visual target CAMEL in list 1, CUDDLE in list 2, CHERRY in list 3 and LORRY in list 4, while *chorry* was followed by the visual target CHERRY in list 1, LORRY in list 2, CAMEL in list 3 and CUDDLE in list 4. Responses to the target words preceded by the phonologically related nonwords (e.g. CAMEL after *cummel*; LORRY after *chorry*) could then be compared with responses to the same words preceded by control nonwords (*chorry*: CAMEL; *cummel*: LORRY). The frequency and phoneme position variables were counterbalanced across presentation orders.

2.2 Subjects

24 undergraduate members of the University of Cambridge community participated in the experiment, in return for a small payment. All were native speakers of Southern British English with no known hearing deficit. Six subjects were tested in each of the four conditions of the experiment.

2.3 Procedure

Subjects were seated in front of a computer monitor and heard the prime words over Sennheiser headphones from tape. 250 ms after offset of each prime word, a letter string appeared on the monitor. Subjects were instructed to listen to the spoken item and then as soon as the visual item appeared to decide as quickly as possible whether the item was a real word of English, and to signal their decision by pressing one of two response keys labelled YES and NO. YES responses were signalled with the preferred hand.

The experiment was controlled by a personal computer running the TSCOP experimental control software. Timing marks aligned with the onset of each visual presentation started the computer's clock, which was stopped by the keypress responses or by a timeout window of 1500 msec.

2.4 Results

Table 1 shows mean response times (RTs) and percentage errors in each of the principal conditions of the experiment. RTs and error rates were subjected to separate analyses of variance across subjects and across items. No priming effects were found; RTs in both vowel and consonant mismatch conditions differed by less than 10 ms from their respective control conditions, and error rates differed by less than 2%. The only RT effect to reach significance across both subjects and items was the interaction of the vowel/consonant mismatch factor with the relative frequency factor: the words mismatching on a vowel were responded to faster when they were of higher frequency of occurrence than the words mismatching on

	Vowel mismatch word higher in frequency		Consonant mismatch word higher in frequency	
	vowel-mismatch (CAMEL)	consonant-mismatch (CUDDLE)	vowel-mismatch (SORROW)	consonant-mismatch (NARROW)
Related prime	<i>cummel</i> 585 (1.3)	<i>cummel</i> 629 (4.6)	<i>sarrow</i> 624 (3.8)	<i>sarrow</i> 618 (6.9)
Control prime	<i>chorry</i> 594 (1.3)	<i>chorry</i> 641 (7.9)	<i>timper</i> 632 (6.7)	<i>timper</i> 601 (3.3)

Table 1. RTs (ms) and error rates, Experiment 1.

a consonant (CAMEL, CUDDLE), but slower when they were of lower frequency (SORROW, NARROW; $F_1 [1,20] = 44.29$, $p < .001$; $F_2 [1,76] = 12.18$, $p < .001$). This is simply an effect of frequency, and it did not interact with the priming comparison. The only error rate effect to reach significance across both subjects and items was the three-way interaction of the vowel/consonant mismatch factor, the frequency comparison and the priming comparison (see Table 1; $F_1 [1,20] = 6.91$, $p < .02$, $F_2 [1,76] = 4.94$, $p < .03$).

Experiment 1 has thus afforded no indication that words can be activated at all by preceding input differing only in a vowel or consonant, let alone any suggestion that vowel versus consonant mismatches might differ in their effects. However, it may also be the case that the cross-modal task is not sufficiently sensitive to phonological priming effects, and that a measure is needed which taps into the spoken-word recognition process itself. Accordingly, in Experiment 2 we addressed the same issue via an auditory lexical decision task. Rather than using paired presentation of auditory primes and auditory targets with responses only to the latter, we used a continuous lexical decision task. Effects of repetition priming in continuous lexical decision are robust, with significant facilitation of responses to an item which has been presented earlier in the experiment [17]. Experiment 2 was carried out in Dutch, which, like English, shows weaker constraints of vowel information than of consonant information in word reconstruction [16].

3. EXPERIMENT 2

3.1 Materials

48 bisyllabic Dutch words were selected for use as target words. As prime words for 24 of them, existing Dutch words were selected which mismatched the targets on only a vowel, on only a consonant, or many segments. Examples are *kaper* ('pirate') for which the primes were *koper* ('buyer'), *kamer* ('room') and *gretig* ('greedy'), or *bobbel* ('bubble') for which the primes were *babbel* ('chatter'), *bochel* ('hump') and *montuur* ('setting'). For the remaining 24 target words equivalent nonword primes were selected; examples are *lepel* ('spoon') for which the primes were *lopel*, *lemel*, *gukte*, or *vonnis* ('judgment') for which the primes were *vinnis*, *vommis*, *malaat*. The experimental targets and their primes may be obtained from the authors. A further 60 words and 108 nonwords, of one to four syllables in length, were selected as filler items. Among these were 24 words forming part of a separate experiment on lexical stress.

All items were recorded by a female native speaker of Dutch, digitised, and stored on disc in a personal computer. Three lists were constructed, each consisting of a short practice set followed by an experimental set containing 132 words and 132 nonwords. On each

list the 48 target words occurred in the same position, but the primes preceding each target word differed. Type of prime was counterbalanced across lists, such that each list contained 16 items (8 word primes, 8 nonword primes) preceded by a vowel-mismatch prime, 16 items preceded by a consonant-mismatch prime, and 16 items preceded by a control prime. Within each such set of 16 items, four primes (2 word primes, 2 nonword primes) preceded the target immediately, four were placed one item back, four were placed two items back, and four were placed three items back.

3.2 Subjects

80 Nijmegen University undergraduates participated in the experiment, in return for a small payment. All were native speakers of Dutch with no known hearing deficit. The responses of two subjects were discarded to counterbalance across the three lists of items such that 26 subjects heard each list.

3.3 Procedure

Subjects were given instructions appropriate to a continuous auditory lexical decision task, i.e. they were instructed to decide for each item as quickly as possible whether the item was a real word of Dutch, and to signal their decision by pressing one of two response keys labelled YES and NO. YES responses were signalled with the preferred hand.

The experiment was controlled by a personal computer running the NESU experimental control software. The items were played from disc to the subjects over Sennheiser headphones and timing marks aligned with the onset of each item started the computer's clock, which was stopped by the keypress responses or by a timeout window of 2500 msec.

Due to an error in one of the experimental sets, the data for two items in the word-prime condition were wrongly coded. All responses to these items were removed from all three sets, leaving 46 items (22 with word primes, 24 with nonword primes).

3.4 Results

Table 2 shows the mean RTs and percentage errors as a function of type of prime (vowel-mismatch, consonant-mismatch, control) and number of intervening items between prime and target (0, 1, 2, 3).

	PRIME TYPE			Mean
	vowel mismatch	consonant mismatch	control	
lag 0	868 (1.0)	847 (2.6)	906 (3.5)	874 (2.4)
lag 1	895 (2.1)	886 (1.7)	900 (3.0)	893 (2.3)
lag 2	906 (2.9)	927 (3.7)	916 (3.3)	916 (3.3)
lag 3	896 (2.9)	918 (3.2)	930 (4.2)	915 (3.4)
Mean	891 (2.2)	894 (2.8)	913 (3.5)	

Table 2. RTs (ms) and error rates, Experiment 2.

The error rate was low (overall mean 2.72%) and errors were not further analysed. RTs, as measured from target word onset, were subjected to separate analyses of variance with subjects and items respectively as random factors. (Note that although word duration has a strong effect on response time in auditory lexical decision, such

effects are irrelevant in the present experiment, where the comparison of interest is not between responses to different items, but between responses to exactly the same item as a function of which prime preceded it.) These analyses revealed no significant effects of whether primes were words versus nonwords, and no interactions of this effect with any other factor. The main effect of number of intervening items was significant across subjects ($F(1, 154) = 9.81, p < .001$), but failed to reach significance across items ($F(2) < 1$). There was however a main effect of prime mismatch condition, significant in both analyses: $F(1, 154) = 4.4, p < .02$; $F(2, 76) = 3.5, p < .04$.

Since the lexical status of the prime had no effect at all, subsequent analyses averaged across this factor. The prime mismatch effect was analysed separately in each lag condition. No significant differences between the three mismatch conditions (vowel-mismatch, consonant-mismatch, control) appeared when any items intervened between prime and target, i.e. in lag conditions 1, 2 or 3. However, in lag condition 0, when the prime immediately preceded the target, significant differences were found: vowel-mismatch primes (*koper: kaper; lopel: lepel*) and consonant-mismatch primes (*kamer: kaper; lemel: lepel*) produced RTs respectively 38 ms faster and 59 ms faster than the control (*gretig: kaper; gukte: lepel*). This facilitation was significant across both subjects and items ($t(1) [77] = 2.18, p < .04$, $t(2) [11] = 2.88, p < .02$; $t(1) [77] = 3.87, p < .001$, $t(2) [11] = 3.74, p < .005$, for vowel-mismatch and consonant-mismatch conditions respectively).

The results of Experiment 2 suggest that some activation of stored lexical representations does occur when a minimally mismatching input is presented. The activation is however short-lived, disappearing after even one intervening word. The facilitation that was observed in lag condition 0 in this experiment contrasts with the results of Experiment 1, suggesting that the cross-modal task was indeed not sufficiently sensitive to register the activation in question; spoken input activates spoken-word representations only.

As in Experiment 1, however, there was in Experiment 2 no evidence that vowel and consonant mismatches produce different effects on lexical activation.

4. CONCLUSIONS

The conclusion of our two experiments is that, as previous research with the lexical decision task has shown, slightly mismatching spoken input can indeed activate stored forms. However, the activation is transitory, and intervening input causes it to disappear. Moreover, the evidence from our study suggests that activation from slightly mismatching spoken input is specific to spoken word forms and cannot transfer to responses to visual input. This latter finding is in agreement with previous results reported for French [20, 21].

Our results suggest that vowel and consonant mismatches exercise equivalent constraints upon activation. In contrast to the findings with the word reconstruction task in both English and Dutch [15, 16], no significant vowel/consonant differences appeared in the present study. In word reconstruction, listeners are required to make conscious alterations to a nonword input in order to reconstruct a real word; our results suggest that it is most probably in the decision processes involved in the alteration operation that the vowel/consonant differences observed with the reconstruction task are located.

The present lexical decision results seem most readily interpreted in the light of the large literature on phonological priming in spoken-word recognition (see, e.g., [13, 14, 20, 21, 22]). This literature contains prior reports of the specificity of the priming effect of

phonological overlap to spoken targets with spoken primes [20, 21], as well as of the transitory nature of the effect [13], and of the equivalence of facilitation by real-word versus nonword primes [21, 22]. Irrespective of the vowel/consonant manipulation, we have thus replicated previous findings of facilitatory effects of phonological overlap in spoken-word recognition.

Interestingly, effects of phonological overlap are not always facilitatory; initial overlaps can inhibit recognition due to competition between simultaneously activated alternative candidate words [6,7,8,13], whereas final overlap facilitates recognition [13,14]. Recent research by Slowiaczek and colleagues [22] has suggested that in monosyllabic words, the strongest priming effects are found when the overlapping portion of the prime and target is the word's rime, i.e. vowel plus coda; recognition of *lamp* is better primed by *damp* than by *lump*. It is in this context noteworthy that although our bisyllabic primes and targets never rhymed, they did always share the rime of the second syllable - indeed in many cases the entire second syllable. Dumay and Radeau [21] also found facilitation with second-syllable overlap in French bisyllables.

The phonological priming literature is not yet agreed upon the locus of the observed priming effects. Certainly the priming does not result from inter-word facilitation, since both in the present study and in earlier work [21, 22], nonword primes and real-word primes exercised equivalent effects. Importantly, Dumay and Radeau [21] found that nonword *targets* were also facilitated by final phonological overlap with a prime, and Slowiaczek et al. [22] refer to unpublished research showing the same result. This suggests that the priming may reflect activation of prelexical phonological units; in the case of a word, this facilitation would flow on to speed word processing, but it would not have its origin in lexical activation. This explanation is certainly consistent with the specificity of the priming effect to the case of spoken targets with spoken primes, and with the transitory nature of the effect. The locus of phonological priming effects is currently a focus of lively debate in spoken-word recognition research, and continuing work will presumably soon further illuminate the issue. The present findings contribute to the debate the knowledge that vowels and consonants participate equivalently in defining phonological overlap.

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