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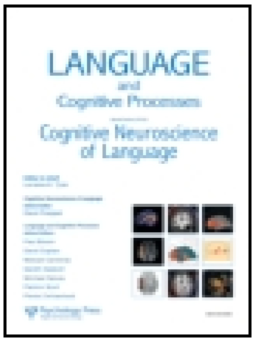

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Bottom-up inhibition in lexical selection: Phonological mismatch effects in spoken word recognition

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Two phoneme monitoring experiments are reported that examine the amount of lexical activation produced by words containing initial, medial, or final mispronunciations. Experiment 1 showed that minimal (one distinctive feature) mismatches in the initial phoneme produced lexical activation relative to a baseline control nonword, but only when the target phoneme was situated at word offset and not word-internally. This finding suggests that considerable bottom-up support is required to override the inhibitory influence of the initial mismatching phonological information. Experiment 2 revealed no lexical activation after a medial mismatch, a finding that is

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consistent with bottom-up inhibition, but inconsistent with models assuming only lateral inhibition. Taken together these findings provide evidence for a selection process which includes bottom-up inhibition as a major component.

Current models generally agree that spoken word recognition involves the activation of a set of lexical candidates and the selection of the target word from this activated set. By all accounts, the amount of activation received by any given word unit—target or competitor—depends upon this unit's fit with the sensory input. This fit reflects the quality and the quantity of the match between the sensory input and the lexical form representation. Models differ, however, in their assumptions about the exact mechanisms underlying the selection process by which the words mismatching the input are eliminated from the candidate set and the correct word is identified.

Two distinct mechanisms of lexical selection have generally been proposed: bottom-up inhibition and lateral inhibition. First, lexical selection can be achieved by means of bottom-up inhibition, like in the original Cohort model (Marslen-Wilson & Welsh, 1978). Under the strongest assumptions, when mismatching sensory information is received, it immediately and completely deactivates the inappropriate lexical units. More recent versions of the COHORT model (Marslen-Wilson, 1987) as well as other models like SHORTLIST (Norris, 1994) have allowed for graded activation that depends upon phonological distance and thus assigned a weaker deactivating influence to mismatching information. Second, lexical selection can take place through lateral inhibition. According to TRACE (McClelland & Elman, 1986), lateral inhibition between lexical competitors allows the best-fitting and most activated candidates, and in particular, the target, to inhibit and deactivate the weaker ones. Finally, bottom-up inhibition and lateral inhibition are not mutually incompatible and can be combined in the same model, as is the case for SHORTLIST.

As a first step in defining empirical tests that evaluate these two mechanisms of lexical selection, it is necessary to identify the main factors that they assume to determine lexical excitation and inhibition. The factor that is most relevant for both mechanisms is the goodness of fit (both in quality and quantity) between the input representation and that of the target lexical representation. The better the fit between these two representations, the greater the activation of the target. Similarly, of course, the poorer the fit, the less activation or—in terms of bottom-up inhibition—the more deactivated the lexical item is. This factor is decisive for determining lexical activation in models assuming bottom-up activation and inhibition.

The second relevant factor concerns the goodness of fit between the input and the representations of the lexical competitors. In models with lateral inhibition, the closer and longer the fit is with lexical competitors, the more the target receives inhibitory influences. In contrast, in models assuming only bottom-up inhibition, this factor should not play a role. These two factors, input to target match and input to competitor match have been termed horizontal and vertical similarity, respectively, by Connine (1994). The present study aims to analyse the mechanisms that underlie the effect of horizontal similarity upon lexical activation.

One common experimental means of testing the contribution of these factors to lexical selection is to introduce mismatches or mispronunciations into the sensory input and to determine the amount of resulting or remaining lexical activation. More specifically, it is useful to vary the degree and position of this mismatching information, since the two selection mechanisms make some different predictions about how vertical and horizontal similarity affect lexical activation. By manipulating the degree of mismatch, it is possible to evaluate the tolerance of the processing system to distortion and to determine whether the system allows graded activation or not. By manipulating the position of the mismatch in the mispronounced word, it is possible to evaluate the importance of competitors in determining the target's activation level. Indeed, when mismatches arrive late in the stimulus, and when there are no more activated competitors, the two mechanisms are differentially relevant. Bottom-up inhibition deactivates the target, whereas lateral inhibition no longer has any impact upon target activation since it cannot operate in the absence of activated competitors. As we will see, models based upon bottom-up inhibition or on lateral inhibition make different predictions.

Spoken word recognition models clearly vary in how well they tolerate initial phonological mismatches in the sensory input. They can range from extreme intolerance and total lexical deactivation by any mismatch in the speech input via bottom-up inhibition, like in the original Cohort model, to relative tolerance and graded activation, like in Shortlist and Trace. The precise predictions of Trace and Shortlist with respect to the effect of initial mismatches upon lexical activation are not well established. It was originally claimed (Elman & McClelland, 1988) that Trace deals with minor initial mismatches efficiently and easily recognises distorted inputs (e.g., "barty" as "party"). However, detailed simulations with Trace (Frauenfelder & Content, 2000) have shown that when presented with nonword inputs that differ from words in a single distinctive feature in their initial phoneme, Trace generally fails to recognise the mispronounced words. Unfortunately, no analogous simulations exist with Shortlist, in part, due to the fact that the model's front end does not take into phonological distance into account. Thus it is difficult to predict the behaviour of Shortlist precisely. Most likely, however, the differences in the predictions for initial mismatches of the two models are more quantitative than qualitative in nature and depend more upon details of implementation than upon fundamental architectural choices.

The experimental literature on the activation of words by inputs mispronounced in their initial phoneme is somewhat contradictory and not yet conclusive. The pattern of results obtained depends upon various factors, including the experimental paradigm used, the type of lexical activation tested (e.g., semantic vs. phonological), the competitor environment and length of the mispronounced word, and the degree of the mismatch. Many studies have focused on the semantic activation produced by initially mismatching inputs using some version of the semantic priming paradigm, either cross-modal or intra-modal (Connine, Blasko, & Titone, 1993; Marslen-Wilson, Moss, & van Halen, 1996; Marslen-Wilson & Zwitserlood, 1989). In these studies, participants made lexical decisions upon either visually or auditorily presented target words that were preceded immediately by a mispronounced semantically related word. Globally, significant priming effects were obtained when the nonword prime was phonologically close to the target word (one distinctive feature difference) and had no other rhyming competitors, suggesting that the factors identified above (match to target and match to competitors) are important.

Other studies have evaluated the effect of initial mismatch upon phonological rather than semantic activation. Connine, Titone, Deelman, & Blasko (1997) used the generalised phoneme monitoring task (Frauenfelder & Segui, 1989) to examine the amount of activation produced by nonwords which varied in their degree of initial mismatch from a target word. The phoneme targets were located in item-final position. The results of these experiments showed a graded effect with decreasing detection latencies for nonwords that were phonologically more similar to words. Interestingly, even the nonwords that deviated from the intended word by several (at least five) distinctive features produced some lexical activation with respect to the unrelated nonword control. It appears that experimental measures of the activation of phonological representations are more sensitive than those of the activation of semantic representations and thus may provide a better basis for testing the proposed selection mechanisms.

The predictions of models based upon bottom-up and lateral inhibition about the impact of later arriving phonological mismatches are more differentiated than those for initial position. For a model like TRACE based upon lateral inhibition, a late phonological mismatch in the input will have little or no effect upon the activation level of the target. Indeed, once the target word has reached a certain level of activation and has no more active lexical competitors that can be reinforced by the mispronounced input, its activation level will be affected minimally by the distortion.

Differences in the activation curves of a target word by an accurate and a mispronounced input are attributable to the fact that the mismatching phoneme provides somewhat less bottom-up support for the target than the appropriate phoneme. In contrast, for models with bottom-up inhibition, the situation is quite different. Late phonological mismatches can deactivate the target word which can only regain in activation strength if there is sufficient subsequent matching input after the mismatch.

Relatively few studies provide information about the deactivation of already activated words by later arriving phonological mismatches. As mentioned above, such studies can, in principle, offer a clean test for bottom-up inhibition that neutralises the influence of lexical competition. Some early research (Zwitserlood, 1989) with the cross-modal semantic priming paradigm has examined the effect of sensory information (/e/) that matches the target (/kapIte/ from kapitein), but mismatches its activated competitor (/kapita:/ from kapitaal, capital). The results showed that activated competitors were immediately deactivated when mismatching information was received. Unfortunately, it is impossible in this study to determine whether it was the mismatching input that eliminated this competitor through bottom-up inhibition or whether the matching target had received sufficient activation from the additional input to inhibit this mismatching competitor. In another cross-modal semantic priming experiment, Connine, Blasko, and Titone (1993) compared the priming effects for initial and medial mismatches in two- or three-syllable words. They obtained effects of similar magnitude for both positions and concluded that initial information is not more heavily weighted or crucial for accessing spoken words.

The present study used the generalised phoneme monitoring task to tap into lexical activation and examine the effect of initial and late mismatches. The way in which detection latencies reflect lexical processing and activation has been a subject of debate in the psycholinguistic literature. Proponents of autonomous models such as Race (Cutler & Norris, 1979) originally argued that the lexical effect observed was the result of an output from the lexical module. Any facilitatory effect of the lexicon required prior recognition of the word, and thus the task was assumed not to be sensitive to early pre-recognition lexical activation. In contrast, Trace includes top-down connections between lexical and phoneme units so that as lexical units gain in activation, they return some of this activation to the phoneme level. Hence phoneme detection latencies are taken to be an early and relatively direct indicator of lexical activation.

One empirical approach taken to test these models is to determine the locus of the lexical effect and to observe its evolution across different target positions. Frauenfelder, Segui, and Dijkstra (1990) found that the effect emerged relatively late, only when the phoneme target was located after the UP. They argued that such late lexical effects, presumably appearing after word recognition, were more consistent with autonomous models. Subsequently, Pitt and Samuel (1995) conducted a similar study in which lexical effects appeared even for targets located before the UP, and they interpreted their findings as supporting interactive models.

More recently, however, Norris, McQueen, and Cutler (2000) have proposed an autonomous model, Merge, in which the lexicon can contribute to the phoneme detection response without assuming an interaction between lexical and phoneme levels of processing. According to this model lexical activation can influence phoneme detection responses relatively early, that is, before word recognition. It now appears then that even autonomous models do not require word recognition for lexical effects to appear. Despite the important remaining theoretical differences between autonomous and interactive processing models, both accounts are in agreement that the differences in phoneme monitoring latencies can be assumed to reflect lexical activation.

In the two phoneme monitoring experiments presented here, we introduce phonological mismatches into words in different positions. We also vary the position of the target to be detected in word and nonword carriers to track the evolution of phonological activation across time. More specifically, Experiment 1 investigates the effect of minimal initial mismatches upon phonological activation for two target positions: late in the items and at item offset. Experiment 2 evaluates the effect of medial phonological mismatches upon phonological activation and tests for bottom-up inhibition under conditions in which the contribution of lateral inhibition is reduced or even eliminated. Deactivation of the target-bearing word by the presence of a medial mismatch would constitute evidence for bottom-up inhibition and would thus argue against models like TRACE that base lexical selection only on lateral inhibition.

EXPERIMENT 1

This experiment tests for lexical activation in initial mismatch conditions by comparing phoneme detection latencies to targets in two positions in words and matched nonwords of two types. The first type, the baseline nonword, has no resemblance to any word and therefore should produce no lexical activation, whereas the second type, the close nonword, is derived from a word by changing a single distinctive feature in the initial phoneme. The difference in detection latencies to the phoneme targets in words and matched baseline nonwords, the so-called lexical effect, represents full lexical activation, whereas the difference between the close nonword and the baseline nonword reflects the partial activation of the word by the close nonword. The position of the target was also manipulated, being either just after the uniqueness point (UP) or at word offset. The UP is defined as that point in a word where the word diverges phonologically from all other words in the lexicon. This manipulation was included to determine whether the lexical effect increases as the target arrives later and more bottom-up support for the target-bearing word has been received.

Method

Participants. Forty-six students of the University of Geneva, all native speakers of French without known hearing deficits, voluntarily participated in the experiment as part of their curriculum. Participants were assigned randomly to each of the four experimental lists.

Materials. Forty-eight polysyllabic French words were selected from the French lexical database, BRULEX (Content, Mousty, & Radeau, 1990) according to two criteria. First, these words had a frequency of at least 100 per 100 million and were thus familiar to the participants. Second, these words contained two different target consonants in their final portion; one just after their UP and one at their offset. Each consonant target never occurred elsewhere in the same item to avoid multiple targets. The targets were liquids (31), stops (31), fricatives (17), and nasals (17).

On the basis of these words, 48 triplets of experimental stimuli were defined: the original words, Close nonwords, and Baseline nonwords. The two types of nonword stimuli were constructed by modifying the original words. Close nonwords were made by changing the first phoneme of the original word by one (and in four cases, two) distinctive features. The resulting nonword point (NWP) of these items was located approximately at the same position as the UP of the original word. Baseline nonwords were constructed by replacing several (at least three) initial phonemes of the original word by other phonemes of the same major phonetic class (a consonant was replaced by another consonant and the same for vowels), thereby retaining the CV structure of the original word. Since only the beginnings of the original words were modified in all nonword items, the local environment of the targets remained identical across the three item types. In this fashion, any detection latency difference between members of a triplet could not be attributed to the local phonological environment of the target (transitional probabilities, syllable frequencies, etc.). An example of an experimental triplet is shown in Table 1 and the lexical and temporal properties of the full stimulus set are given in Table 2. In summary, the test stimuli can be characterised in terms of three main factors: activation type (full vs. partial), position (first vs. second) and

TABLE 1

Examples of stimuli, mean RTs in ms and percentage correct responses for the different experimental conditions in Experiment 1 (target phonemes in bold and mismatching phonemes underlined)

		Lexicality	
Target position	*Activation condition*	*Baseline Nonword*	*Word/Close Nonword*
First	Full	*sat*oby**l**ɛʀ 461.3 (94.6)	vokaby**l**ɛʀ 412.9 (95.5)
	Partial	*sat*oby**l**ɛʀ 459.0 (95.3)	*f*okaby**l**ɛʀ 460.0 (93.8)
Second	Full	*sat*obylɛ**ʀ** 405.2 (96.4)	vokabylɛ**ʀ** 309.3 (97.8)
	Partial	*sat*obylɛ**ʀ** 403.6 (94.2)	*f*okabylɛ**ʀ** 364.3 (93.1)

lexicality (Baseline nonword vs. Word or Close nonword). The Appendix lists the experimental stimuli and targets.

In addition to the 48 triplets of test items, 216 fillers (words and nonwords) were also created to include items without targets and to vary further the target position. There were 48 words and 96 nonwords without targets. In addition, 48 words and 24 nonwords were also included with targets in early word positions (word onset, first and second consonant positions after word onset) to prevent participants from expecting target phonemes towards the end of the item. All fillers were similar to the test items in their global phonological make-up and syllable structure.

Four experimental lists which each contained a subset of the test items were created. Each list contained two members of an experimental triplet: the baseline nonword and either the matching word or the close nonword. This latin-square design made it possible to avoid any priming effects that

TABLE 2

Lexical (uniqueness point and nonword point and cohort size) and durational properties (and their SD) of the stimuli used in Experiment 1

	UP/NWP (No. of phonemes)	*Cohort size (No. of words)*	*Distance from onset to target 1 in ms*	*Distance from onset to target 2 in ms*
Words	4.48 (0.77)	10.88 (11.69)	531.4 (111.6)	881.4 (146.5)
Close nonwords	3.92 (0.94)	16.04 (25.88)	556.9 (124.5)	907.0 (167.2)
Baseline nonwords	4.21 (0.74)	15.79 (22.88)	587.2 (145.6)	940.3 (180.0)

might have arisen in presenting an original word and its derived close nonword to the same participant. The test items were assigned to the four experimental lists so that each list contained an equal number of items (12) from each condition. In addition, the groups of 12 stimuli were divided such that they varied in the nature of the target phoneme (e.g., stops, liquids, etc.). The resulting 336 stimuli were arranged in four pseudo-randomised blocks of 84 items. The word or the close nonword items were assigned to blocks such that they were separated from their corresponding baseline nonword by at least one block. These blocks were presented in the same order to all participant groups.

Procedure and apparatus. The stimuli were recorded on DAT-tapes by a native speaker of French and then transferred to the hard disk of a computer at a sampling rate of 16 KHz. The experimental lists that were created by adding target specifications and warning beeps were then re-recorded on DAT tapes. Response times were recorded by an AST 4/25 SL laptop running the NESU (Nijmegen Experimental Set-Up) software package, developed at the Max-Planck Institute (Nijmegen, the Netherlands).

Participants were tested individually or in groups of two or three. They first heard the target specification (the consonant target produced in its default syllable context and a name beginning with the target—e.g., "/l/ as in Lara"). Then they received a short warning tone followed by a pause of 50 ms and finally the test (or filler) item. Participants had 2500 ms from item onset to respond. A 2 s pause preceded the next trial. Between each block of 84 items there was a short break of approximately 3 min. Participants received written instructions and then performed 20 warm-up trials. They were instructed to push on the response button with the index finger of their dominant hand as quickly as possible when they heard the target phoneme.

Results

Reaction times (RTs) were measured from the onset of the target phoneme, which was determined both auditorily and visually using a waveform editor. Response times faster than 100 ms or slower than 1000 ms were discarded from the analysis. No participants were excluded from the analysis; all had an error rate of less than 15%. Mean RTs and mean per cent correct (PC) scores were calculated separately for each subject and item. Overall mean RTs and PC scores for the main experimental conditions are given in Table 1. The close match between the two corresponding RT means in the baseline nonword conditions indicates that they provide a highly stable measure for evaluating the lexical effect.

Three-way ANOVAs were performed on the PC and RT data with the factors, activation, position, and lexicality. No main effects were fully significant in the error analyses, but the interaction between activation and position was marginally significant [$F_1(1, 45) = 6.22$, $p < .02$]. All three factors, however, showed highly significant main effects in RTs both by-subject and by-item: activation [$F_1(1, 45) = 25.66$, $p < .0001$]; [$F_2(1, 47) = 15.97$, $p < .001$], position [$F_1(1, 45) = 132.55$, $p < .0001$]; [$F_2(1, 47) = 59.75$, $p < .001$], and lexicality [$F_1(1, 45) = 92.82$, $p < .0001$]; [$F_2(1, 47) = 46.38$, $p < .001$].

More importantly, two significant interactions were also found: lexicality and position [$F_1(1, 45) = 38.05$, $p < .001$; $F_2(1, 47) = 12.77$, $p < .001$] and activation and lexicality [$F_1(1, 45) = 39.86$, $p < .001$; $F_2(1, 47) = 41.66$, $p < .001$]. The other interactions, including the triple interaction were not significant ($F < 1$).

The two significant interactions have a coherent interpretation. The interaction between lexicality and position clearly shows that lexical activation increased as the listener received more sensory input. The interaction between lexicality and activation shows that there is a greater lexical effect for words than for the close nonwords. Globally, the word condition showed a 72 ms effect, whereas the close nonword condition produced only a 20 ms advantage.

Figure 1 shows RT differences that correspond to the lexical effect for full and partial activation conditions in the two target positions. Specific comparisons in the full activation condition showed a significant effect for both target positions: position 1 [$F_1(1, 45) = 23.47$, $p <.001$; $F_2(1, 47) = 28.78$, $p < .001$] and position 2 [$F_1(1, 45) = 92.06$, $p < .001$; $F_2(1, 47) = 111.12$, $p < .001$]. In contrast, for the partial activation condition, the lexical effect was significant for position 2 [$F_1(1, 45) = 15.49$, $p < .001$; $F_2(1, 47) =17.69$, $p < .001$], but not for position 1 (both Fs < 1).

Discussion

This first experiment measured monitoring latencies to phoneme targets in two different positions to track lexical activation across time. It compared the size of the lexical effect produced in the full and partial activation conditions. As expected, robust lexical effects were found for both target positions in the full activation condition. Moreover, the lexical effect increased as the target arrived later in the item. In contrast, a significant lexical effect for stimuli containing a minimal initial mismatch was only obtained when the target was located in final position of the target-bearing item. When the target phoneme occupied the earlier position, just after the UP, no lexical effect was found for close nonwords.

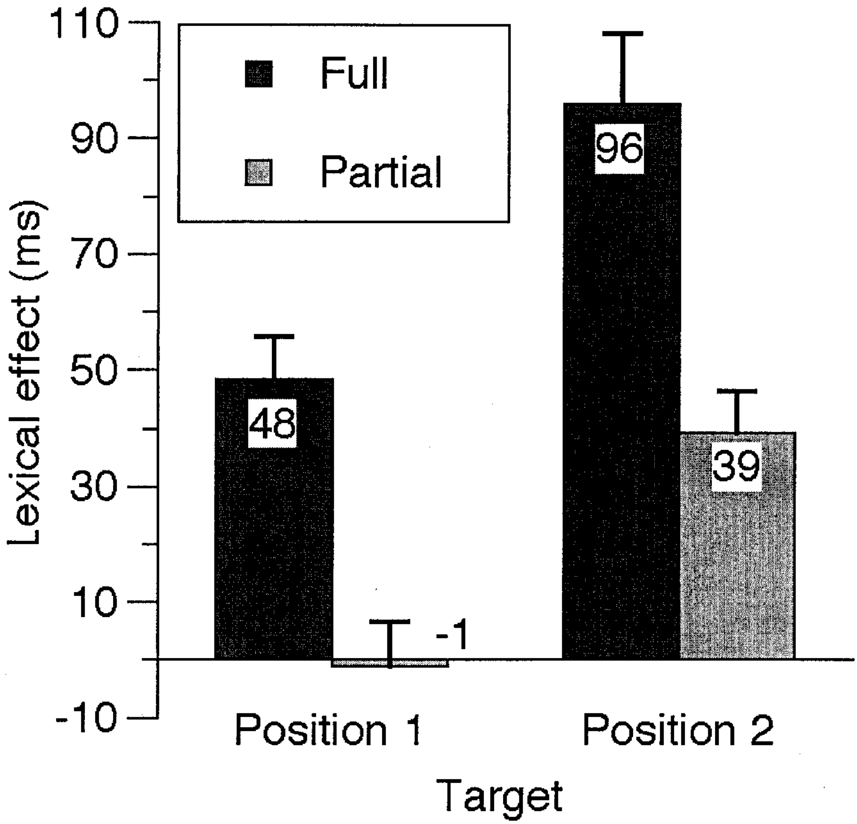

Figure 1. RT differences and error bars for the Full activation (words) and Partial activation (close nonwords) conditions relative to the Baseline nonwords for the two target positions in Experiment 1.

Two observations can be made about the results for the full activation condition. First, our finding of an increasing lexical effect with later target positions in this condition replicates a well-established result in the literature (Frauenfelder et al., 1990; Marslen-Wilson, 1984; Pitt & Samuel, 1995). As more bottom-up input supporting the target bearing word arrives, even after the uniqueness point, the target's activation level continues to increase. Second, the decrease in the detection latencies observed in the baseline nonword condition for the final target position might appear to be somewhat surprising. One might expect that since the lexicon does not contribute to the detection responses for these items, the latencies should be constant across target position. However, it is important to note that the two target positions are not identical from a bottom-up perspective. In particular, there is no following acoustic information to mask the target in item final position, and therefore the detection process is quicker. This finding of faster RTs to item final targets is, in fact, rather consistently observed (Frauenfelder et al., 1990; Pitt & Samuel, 1995).

For the partial activation condition, the demonstration of a lexical effect for the close nonwords in the second position condition is important. First, this result replicates, with a larger variety of targets, the findings of Connine et al. (1997) and produces an effect that is approximately equivalent in size (40–50 ms) to the one they observed for the final position of trisyllabic items used in their Experiment 1. We found no lexical effect for the earlier target position. This suggests that insufficient bottom-up evidence had accumulated by the time this target arrived to override the inhibitory effect of the initial mismatching phoneme.

The present findings provide further evidence against models like the original Cohort model, which are totally intolerant of phonological mismatches. Indeed, in such models any initial mismatch—even minimal—is sufficient to prevent the intended word from becoming activated and to exclude it from the competitor set. These findings, however, are also consistent with an alternative account which attributes the lexical effect obtained for the partial activation condition in final position to a late second-pass recovery mechanism (Marslen-Wilson, 1993). One diagnostic that has been proposed to distinguish second-pass from more perceptual first-pass accounts is the range of the observed RTs. The detection latencies that we observed were rapid (less than 450 ms) and fall well below the 700 ms cut-off proposed for perceptual accounts by Connine et al. (1997), making a post-perceptual explanation somewhat unlikely. In other experimental paradigms like mispronunciation detection in which participants are required to determine under time pressure whether experimental items are mispronounced or not, the RTs are considerably longer than those obtained here, suggesting a possible post-perceptual locus. However, it is important to remain cautious, since as pointed out by Connine et al. (1997), speed-based criteria for distinguishing these two types of explanations must be made more explicit to be useful. Finally, it should also be noted that the speed of any second-pass response most likely depends upon the amount of lexical activation that has been produced by the nonword input. In this sense, the RT difference observed may well reflect the amount of initial lexical activation, even if the response is based upon a second-pass strategy.

Regarding the predictions of computational models for initial mismatches, we have already pointed out that the simulation results for Shortlist and Trace are not well established. Unlike what is commonly assumed, our simulations (Frauenfelder & Content, 2000) showed that Trace's recognition performance was globally quite poor for stimuli with small initial phonological mismatches. Indeed, when an activation level of 0.50 was taken arbitrarily to represent the recognition threshold, few words (22%) were recognised. These mispronounced words were nonetheless somewhat activated since their activation level rose above their resting threshold. The question remains of how to relate such simulated activation to that measured in experiments. Given that the predictions of the models are not clearly differentiated and depend upon internal factors like the parameter settings and external factors like the stimulus set, the present data do not discriminate between the two competing models.

As mentioned in the Introduction, TRACE and SHORTLIST diverge much more clearly in their predictions for medial mismatches than for initial mismatches. For SHORTLIST, the presence of word-internal mismatching information in the signal produces bottom-up inhibition that strongly deactivates the lexical target. In contrast, since the target word no longer has any lexical competitors when the mismatching information is received, TRACE predicts no difference between the activation curves for word and nonword conditions due to lateral inhibition. The predictions of the two models were confirmed by pilot simulations (Frauenfelder & Content, 2000). The activation curves produced by SHORTLIST decreased dramatically at the moment when the mismatching phoneme is received and remained only weakly activated for the remaining input. It is important to note that unlike the quantitative differences in models' predictions for Experiment 1, the predictions here are qualitatively different and result from explicit architectural choices on activation flow.

EXPERIMENT 2

This experiment tested for the existence of bottom-up inhibition by introducing mismatching information medially or finally into the same words as were used in Experiment 1. The location of the target phoneme with respect to the mismatching phoneme was varied: either the target preceded ("preceding mismatch" condition) or the target followed ("following mismatch" condition) the mismatching information. In both conditions, one of the phonemes that served as a target in Experiment 1 retained that role (/l/ or /r/ in vocabulaire) and the other was replaced by an inappropriate phoneme (/r/ to /z/ or /l/ to /n/ giving "vocabulaise" or "vocabunaire"), which differed from the original one by several distinctive features.

As in the previous experiment, the size of the lexical effect in the partial activation condition was compared with that in the full activation condition using a matched baseline nonword. The "following mismatch" condition provides a test of bottom-up inhibition accounts which predict a strong decrease in the lexical effect for the partial activation condition. The "preceding mismatch" condition should give some information about the temporal resolution of the phoneme monitoring task. If the phoneme monitoring response is immediate and rapid, we expect no interference by later arriving mismatch information. Consequently, lexical effects of equal size in the full and partial conditions are expected, if the detection latencies directly reflect lexical activation at the moment that the target comes in.

Method

Participants. Forty students of the University of Geneva, all native speakers of French, without known hearing deficits, voluntarily participated in the experiment as part of their curriculum. Participants were assigned randomly to one of the four experimental lists.

Materials. The same 48 original test words from Experiment 1 were used to construct the nonword stimuli of this experiment. The relevant experimental comparisons, target preceding mismatch and target following mismatch with their full activation controls, are illustrated in Table 3 and a description of the lexical and temporal properties of the nonword stimuli used are given in Table 4.

In the first set of comparisons, the target preceded the mismatching phoneme. The target was the same as that used for position 1 in Experiment 1 and a mismatching phoneme differing in two or three phonological features was substituted for the phoneme that served as the target in position 2. The same phoneme substitution was also performed in the baseline nonwords of Experiment 1 to create matching baseline

TABLE 3

Examples of stimuli, mean RTs in ms and percentage correct responses for the different experimental conditions in Experiment 2 (target phonemes in bold and mismatching phonemes underlined)

		Lexicality	
Target position	*Activation condition*	*Baseline Nonword*	*Word/mismatch Nonword*
Preceding mismatch	Full	*sat*oby**l**ɛʀ 465.4 (94.8)	vokaby**l**ɛʀ 410.5 (96.3)
	Partial	*sat*oby**l**ɛ*z* 474.3 (94.6)	vokaby**l**ɛ*z* 440.5 (94.8)
Following mismatch	Full	*sato*bylɛ**ʀ** 394.6 (96.7)	vokabylɛ**ʀ** 328.7 (96.7)
	Partial	*sato*by*n*ɛ**ʀ** 428.9 (96.3)	vokaby*n*ɛ**ʀ** 423.6 (95.8)

TABLE 4
Lexical (uniqueness point and nonword point) and durational properties (and their SD) of the stimuli used in Experiment 2

Target position	*Nonword*	*NWP (No. of phonemes)*	*Distance to target in ms*
Preceding mismatch	Mismatch	(7.75) (0.89)	527.9 (108.2)
	Baseline	4.21 (0.74)	578.9 (137.5)
Following mismatch	Mismatch	(5.63) (0.89)	916.1 (165.4)
	Baseline	4.21 (0.74)	962.0 (185.8)

nonwords. Similarly, for the experimental comparison in which the target followed the mismatch, the targets corresponded to the position 2 targets of Experiment 1 and a mismatching phoneme was substituted for the phoneme that served as the target in position 1.

The choice of the substituted phoneme depended upon its phonological distance (2 to 3 distinctive features) from the original phoneme as well as upon the frequency of the resulting item-final syllable. Thus, the average frequency of the final syllable of the mismatch conditions (e.g., /lɛz/) approximated that of the full activation condition (e.g., /lɛr/) as closely as possible. This control was included in order to eliminate possible syllable frequency effects upon detection latencies. However, the critical comparisons for estimating the lexical effect in the full and partial conditions were based on the same target-bearing syllable (e.g. /lɛz/ in vocabulaize and satodulaize). All other aspects of materials, including the fillers and foils as well as the preparation of the four experimental lists were identical to those in Experiment 1. The Appendix lists the experimental stimuli and targets.

Procedure. All procedural aspects were the same as in Experiment 1.

Results

Mean RTs were computed from target phoneme onset for each subject and each experimental item. RTs below 100 or above 1000 ms were eliminated from the analysis. The mean RTs and percent correct (PC) scores for all conditions are shown in Table 3.

Target preceding mismatch. A two-way ANOVA was conducted using the RT data with lexicality and activation as the main factors. This analysis yielded main effects of activation [$F_1(1, 39) = 11.25$, $p < .001$; $F_2\ (1, 47) = 4.64$, $p < .001$] and lexicality [$F_1(1, 39) = 45.91$, $p < .001$; $F_2(1, 47) = 20.36$, $p < .001$]. The interaction between these two factors was only significant by item [$F_1(1,\ 39) = 2.3$, $p < .14$; $F_2(1,\ 47) = 5.44$, $p < .05$]. Specific comparisons in the full activation condition showed a significant lexical effect [$F_1(1, 39) = 31.35$, $p < .001$; $F_2(1, 47) = 51.48$, $p < .001$]. For the partial activation condition, the lexical effect was also significant, although numerically reduced as shown in Figure 2 [$F_1(1, 45) = 11.93$, $p < .05$; $F_2(1, 47) = 15.03$, $p < .05$]. The fact that the interaction was significant in the item and not the subject analyses suggests the need to conduct more detailed analyses of the inter-individual variation. This analysis is presented in the discussion of Experiment 2. There were no significant differences in an ANOVA on PC scores.

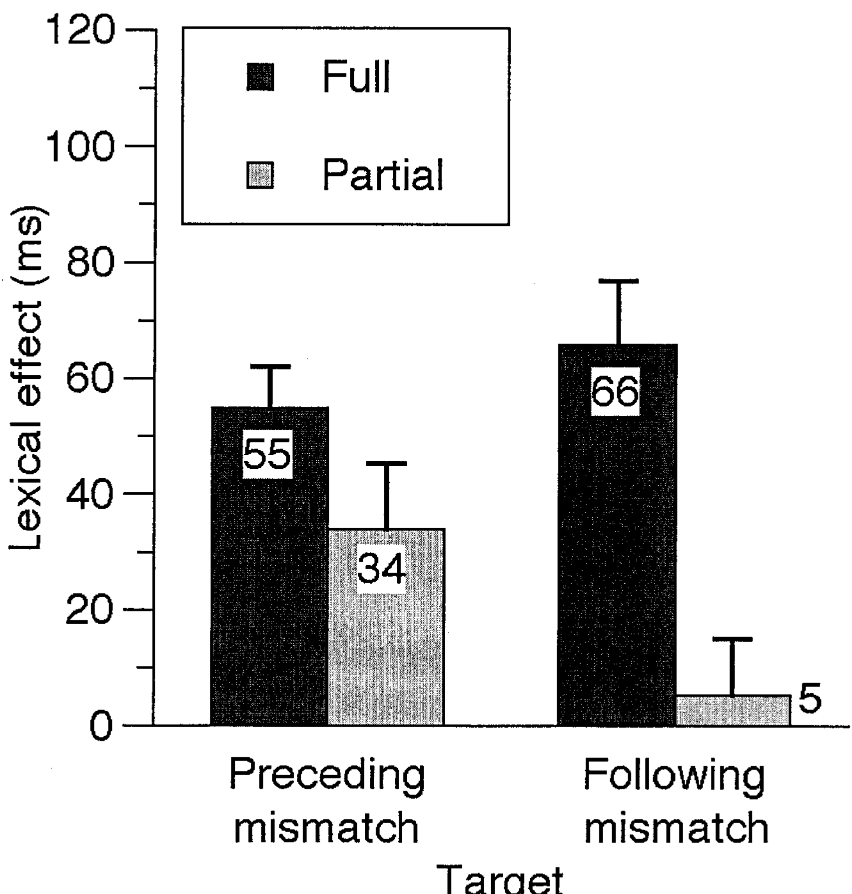

Figure 2. RT differences and error bars for the Full activation (words) and Partial activation (mismatching nonwords) conditions relative to the Baseline nonwords for the two target positions in Experiment 2.

Target following mismatch. A two-way ANOVA was conducted on the RT data with lexicality and activation as the main factors. This analysis yielded main effects both by-subject and by-item for activation [$F_1(1, 39) = 83.75$, $p < .001$; F_2 $(1, 47) = 36.41$, $p < .001$] and lexicality [$F_1(1, 39) = 25.50$, $p < .001$; $F_2(1, 47) = 11.98$, $p < .001$]. The interaction between these two factors was also significant [$F_1(1, 39) = 16.22$, $p < .001$; $F_2(1, 47) = 7.01$, $p < .01$]. There were no significant differences in an ANOVA on PC scores (Fs < 1). As illustrated in Figure 2, a highly significant difference was obtained for the full activation condition as confirmed by the local comparisons [$F_1(1, 39) = 38.39$, $p < .0001$; $F_2(1, 47) = 17.39$, $p < .0001$], but no lexical effect was found in the partial activation condition [both Fs < 1].

Discussion

This experiment has examined the impact of mismatching information located either medially or finally. The position of the target was varied with respect to the position of these mismatches. In what follows, we will first discuss the critical condition in which the target follows the phonological mismatch. We looked for a deleterious influence of this mispronunciation on lexical activation and indeed, the results showed no lexical effect, that is, no significant difference between mismatching nonwords and baseline nonwords. Since a clear lexical effect was obtained in the corresponding full activation condition in this experiment as well as in Experiment 1, we can be certain that the target-bearing word is clearly activated at the moment that the mismatching phoneme arrives. Consequently, the absence of a lexical effect in the partial activation condition suggests that the activated word has been deactivated by this mismatching information via bottom-up inhibition.

An alternative explanation for the absence of RT differences in this partial activation condition appeals to the attentional consequences of the mismatch on the detection process, what we will term a ‘‘surprise effect’’. Here, the phonological mismatch surprises participants and hence delays their responses to targets which arrive immediately after this mismatch. Although it is difficult to choose between this surprise account and the bottom-up inhibition explanation (or the combination of both) on the basis of the data presented here, they make different predictions concerning the size and direction of the lexical effect in the partial activation condition, and its relation to the size of this effect in the full activation condition.

First, according to a bottom-up inhibition account, detection performance should never be slower for the mismatch items than for their baseline nonword control. Inhibition can only reduce or eliminate the lexical effect, but not reverse it. In contrast, according to a surprise effect explanation, the disruptive influence of the mismatch can, in principle, produce slower RTs in the mismatch condition relative to the baseline condition, overriding any lexical facilitation produced by the initial part of the mismatching stimuli. Thus, the absence of a reversed lexical effect in the overall RT pattern provides no support for the surprise explanation.

A more subtle way to distinguish between the two accounts refers to the correlations between the lexical effects in the full and partial activation conditions. According to the bottom-up inhibition account, highly activated words which receive some bottom-up inhibition still retain a relatively high level of activation. Hence, there should be a positive correlation between the lexical effects in the full and partial activation conditions. In contrast, for the surprise account, the larger the lexical activation, the more likely the participants are to have anticipated the word and to be negatively affected by violations of their expectations. Thus, a negative correlation should be found between the lexical effects for the full and partial conditions. Globally, the observed correlation was non-significant and close to zero ($r = -.065$, ns), thus providing no support for either account.

In a further analysis we examined this correlation for two subgroups of subjects which were defined on the basis of the speed of their bottom-up processing using the mean RTs for baseline nonwords. We expected that this variable would be related to the amount of attention devoted to the speech input. These attentional differences might condition the presence of a surprise effect: the more closely the participant pays attention to the input, the more likely an unexpected mismatch will be noticed and create a surprise. We thus defined two subgroups based on a median-split on the average response latencies across all nonword baseline conditions.

Figure 3 (right panel) presents the scatterplot showing the relation between the lexical effects in the full and partial conditions for the two groups. For the fast group, the resulting correlation ($r = -.324$, $p = .17$) was negative, although not significant. The lexical effect in the full activation condition was 67 ms ($SD = 56$; 282 and 349 ms, respectively, for the words and baseline nonwords). In the partial activation condition a negative −16 ms trend in the opposite direction was observed ($SD = 71$; 396 and 380 ms, for the mismatch and baseline nonwords). This suggests that among the rapid participants, those showing the largest lexical effect in the full activation condition were most detrimentally affected by the mismatch in the partial activation condition. The finding of a negative lexicality effect together with a negative correlation may be consistent with a surprise effect explanation. However, as can be seen from the figure, the negative slope and mean effect are essentially due to three participants. When these participants were eliminated, the mean effect was 8 ms. ($SD =$ 40) and the correlation was clearly non-significant ($r = -.15$, $p > .50$).

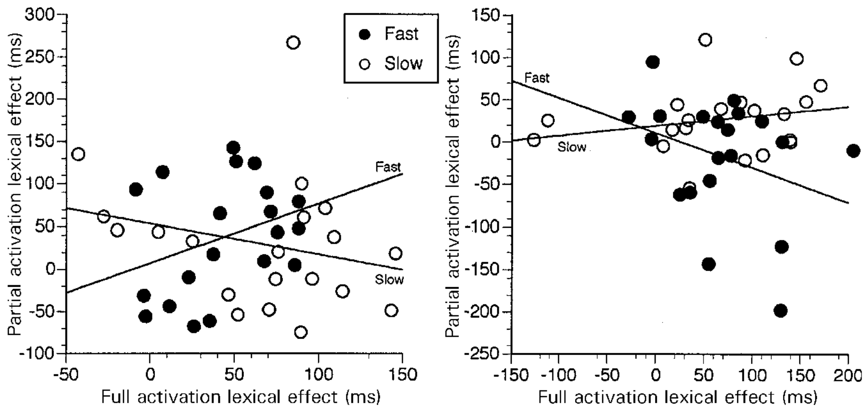

Figure 3. Scattergram for fast and slow participants of lexical effects in the full vs. partial activation condition for the target preceding the mismatch (left panel) and the target following the mismatch (right panel) conditions.

For the slow group, the relation was positive ($r = .236$, $p = .32$), and the mean lexical effects in the full and partial activation condition were 65 ms ($SD = 81$; 375 and 440 ms) and 27 ms ($SD = 41$; 451 and 478 ms). The slow participants who showed the largest lexical effect in the full activation condition also showed the most residual activation for the partial condition. The decrease in the lexical effect from the full to the partial activation condition together with the positive correlation is consistent with a bottom-up inhibition account. Taken together, the results for the preceding mismatch condition suggest that the surprise effect exists, but is limited to fast participants. Given the pattern obtained for the slow group, the most parsimonious interpretation is that bottom-up inhibition plays a role in both groups, but is modulated by a surprise effect for the fast group.

For the condition in which the target preceded the mismatching information (Figure 3, left panel), a significant but reduced lexical effect was found for the partial activation condition. However since this reduction was not significant in the subject analysis, we conducted a more detailed analysis of the inter-individual variation. We predicted that the faster group would be less sensitive to the later arriving mismatch information than the slower group which should be slowed down by the mismatch either due to bottom-up inhibition or to a surprise effect. The analyses confirmed these predictions. Fast participants showed no difference in the size of the lexical effect for the full (group mean 44 ms, $SD = 32$; 363 vs. 407 ms) and partial activation (group mean 38 ms, $SD = 68$; 385 vs. 423 ms) conditions and the correlation was positive ($r = .331$, $p = .16$). It is interesting to note that the interval that separates the onset of the target from the onset on the mismatching phoneme is around 400 ms.

In sum, fast participants launched their detection response before the mismatch information was received so that no reduction in the lexical effect was observed.

In contrast, for the slower participants the lexical effect showed a marked decrease from the full activation (group mean 66 ms, $SD = 54$; 458 vs. 524 ms) to the partial activation condition (30 ms, $SD = 78$; 496 vs. 526 ms) and the correlation was not significant ($r = -.246$, $p = .30$). These results suggest that for the slow participants the mismatch information still arrives in time to have a negative impact on detection performance.

Returning to the condition of central interest, the following mismatch condition, we have found some evidence that medial mismatch has a major disruptive influence upon the detection of later arriving phonemes. In light of the predictions made by the TRACE and SHORTLIST simulations, the absence of a lexical effect for the words containing medial mismatching information supports SHORTLIST over TRACE. Indeed, whereas TRACE predicts little or no effect of the mismatch, SHORTLIST predicts the observed deactivating effect of the mismatch information.

GENERAL DISCUSSION

Two main issues have been addressed here: The extent to which initial mismatching information prevents later-arriving matching information from activating a target word and the extent to which later-arriving mismatching information reduces the activation produced by earlier matching information. The first experiment revealed some lexical activation despite the presence of an initial mismatch, but only after considerable bottom-up matching information was accumulated. Thus a lexical effect was observed only for item-final targets but not for item-medial ones. The second experiment showed that a phonological mismatch coming late in a stimulus item has a strong negative impact upon lexical activation, in effect, eliminating any trace of a lexical effect in the detection latencies.

This study has used the phoneme monitoring task to tap into the activation of phonological representations in the lexicon produced by mispronounced tokens of these words. An important methodological issue that still remains to be addressed involves comparing the measures of lexical activation based on phonological and semantic representations as they are generated by phoneme monitoring and cross-modal semantic priming, respectively. This analysis is all the more urgent given the lack of convergence in the findings obtained with these tasks. Indeed, we have a somewhat contradictory situation in which the phoneme monitoring task appears to provide a more sensitive measure of lexical activation, for example, revealing lexical activation by initial phonological mismatches for which no activation was observed with the semantic priming paradigm. In contrast, the reverse seems to be the case for the later arriving mismatches. Our phoneme monitoring findings show no trace of lexical activation for these mismatches, whereas cross-modal priming experiments (Connine et al., 1993) have measured priming effects that are significant and similar in magnitude to those for initial mismatches.

In the absence of more systematic comparisons between these tasks, however, we can only propose a number of task properties which need to be taken into account to clarify this paradoxical situation. First, the present findings suggest that the behaviour observed in the phoneme monitoring task is rapid and closely time-locked to the signal. Indeed, the results from the "preceding mismatch" condition in the second experiment show that rapid participants respond before the mismatch information arrives and thus are not affected by it. In contrast, the participants who respond only 100 ms more slowly on average, but who have processed the mismatching information, are strongly affected. This reveals the sensitivity of the phoneme monitoring response to on-going lexical activation. Unfortunately, however, despite having an experimental tool with considerable temporal sensitivity, the researcher generally cannot be certain of what stage of processing is actually being tapped into. In the first experiment, the temporal interval separating the mismatching initial phoneme and the phoneme target (approximately 500 ms) is sufficiently great that many different processing steps could have taken place, including perhaps second pass processing. This suggests that measuring rapid RTs is a necessary, but not sufficient condition for testing perceptual processing. The temporal distance between the onset of the process of interest and of response generating the dependent variable is also crucial. In the present context, then, this means that the phonological mismatch and the target should be put in close temporal proximity.

However, the second experiment, in particular, the "preceding mismatch" condition, points to a possible limitation of this approach since it may introduce contaminating attentional effects. Participants detecting phonemes must focus their attention on the phonemic level, the same level as that of the phonological mismatch. Moreover, since the target and mismatch are in close temporal proximity, attentional and not only perceptual consequences of the mispronunciation may be measured as interference or surprise effects. Although our results provide only limited support for the role of attentional factors, this possibility should be examined more systematically.

Semantic priming obviously requires that activation reach the semantic level presumably via a series of processing steps. In most current conceptions of lexical processing, the activation of semantic information follows phonological activation, and so the amount of excitation reaching the semantic level may be less. This may explain the greater sensitivity of phonologically based measures. However, a comparison of semantic and phonological priming at different SOAs is needed to test this explanation and to obtain more detailed information on the relative time-course of semantic and phonological activation. With respect to measuring the deactivating effects of medial phonological mismatches, it is less clear that cross-modal semantic priming is an appropriate tool. In the framework that we have adopted, bottom-up inhibition depends upon the phonological match between the signal and the target lexical form representation. Although the link between phonological and semantic activation is not well understood, there is no reason to believe that even an extremely abrupt decrease of activation at the phonological level should immediately erase all activation at the semantic level.

One of the basic goals in the study of spoken word recognition is characterising the nature of the information flow which allows lexical selection and recognition. We have identified two possible component mechanisms of lexical selection, one based on bottom-up inhibition and the other on lateral inhibition. Our experimental results have focused on the former and indicate that spoken word recognition models need to include some form of bottom-up inhibition. The presence of a medial mismatch completely eliminated the lexical effect, a result which can be accounted well for in terms of a bottom-up inhibition mechanism. However, more precise analyses of the lexical effect in the full and partial conditions do not rule out the contribution of a ‘‘surprise effect’’ to the disappearance of the lexical effect. The results from the first experiment point to the importance of bottom-up match that may compensate for the initial mismatch. A large number of matching phonemes (at least six that on average separate the mismatching initial phoneme and the item final target) is required to overcome the initial mismatch and permit lexical activation. Findings such as these should contribute to the setting in computational models of parameters related to the connection strengths of bottom-inhibition and activation, and perhaps lateral inhibition.

The present experiments have not included a test of lateral inhibition. However, other studies have shown that lateral inhibition plays a role in lexical activation and processing. Priming studies by Goldinger, Luce, and Pisoni (1989) and Goldinger, Luce, Pisoni, and Marcario (1992) show that the recognition of a word is slower when it is preceded by a phonologically similar word than by a dissimilar word. This inhibition is most likely attributable to competition between the prime and target. More direct evidence for competition effects has been provided in a word spotting experiment (McQueen, Norris, & Cutler, 1994). Here, the recognition of a non-initial embedded word (e.g., *mess*) was delayed by its overlapping competitor (e.g., *domestic)*. The longer spotting latencies for the words embedded in word fragments suggest not only that words with different alignments (carrier and embedded words) are activated simultaneously, but also that the longer carrier word competes with and inhibits the embedded word.

Putting these findings supporting lateral inhibition together with our results in favour of bottom-up inhibition, we arrive at a picture of the selection process that is based on a combination of both types of activation flow—as in SHORTLIST. Clearly, it will be important in future studies to determine the relative importance of these two components in the lexical selection process. More detailed simulations with improved computational implementations of TRACE and SHORTLIST, in particular, with more complete front-ends, are vital for producing the appropriate simulation data. Such research would help clarify the rather vague predictions made about lexical activation for initially mispronounced words. Additional experimental data on the temporal evolution of lexical activation are also needed. The present monitoring results constitute a first step in understanding this temporal evolution, with two measures of lexical activation for the same word. Unfortunately, however, they are insufficient to identify the complete activation function, and thus more continuous measures, probably with another experimental technique, are needed.

In sum, the present findings provide some further constraints upon the architecture of localist models of spoken word recognition. They point to an important distinction between quantitative and qualitative differences in the predictions of computational models. The former, like those concerning the effect of initial mismatches, depend upon parameter setting and implementational details whereas the latter, related to the effects of medial mismatches, reflect fundamental choices in the models' architecture. With respect to the latter, these cast some doubt on models like TRACE that rely exclusively on lateral inhibition. Such models cannot account for the strong deactivation by medial mismatches. Future research efforts must attempt to characterise the delicate balance between bottom-up activation, bottom-up inhibition, and lateral inhibition.

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APPENDIX

Experimental stimuli (targets in bold) for Experiments 1 and 2

Experiments 1 and 2		*Experiment 1*	*Experiment 2*			
Word	*Baseline nonword*	*Close Nonword*	*Mismatching nonword*	*Baseline nonword*	*Mismatching nonword*	*Baseline nonword*
majuscule	somiscule	najuscule	majuscutte	somiscutte	majusrule	somisrule
crocodile	spamodile	trocodile	crocodise	spamodise	crocochile	spamochile
géranium	dolanium	cheranium	géraniutte	dolaniutte	gérasium	dolassium
baïonnette	chuïonette	païonnette	baïonème	chuïonème	baïoRette	chuïoRette
labyrinthe	numorinthe	nabyrinthe	labyring	numoring	labysinthe	numosinthe
dictionnaire	fulkionaire	tictionnaire	dictionaime	fulkionaime	dictiojairre	fulkiojaire
vocabulaire	satodulaire	focabulaire	vocabulaine	satodulaine	vocabunaire	satodunaire
mademoiselle	birgoiselle	nademoiselle	mademoisette	birgoisette	mademoimelle	birgoimelle
albinos	oclinos	`elbinos	albinol	oclinol	albivos	oclivos
gladiateur	flodiateur	cladiateur	gladiateup	flodiateup	gladiameur	flodiameur
marmelade	sègmelade	narmelade	marmelaf	sègmelaf	marmesade	sègmesade
référendum	sircilendum	léférendum	référenduk	sircilenduk	référenfum	sircilenfum
légionnaire	gafionnaire	dégionnaire	légionnaitte	gafionnaitte	légiolaire	gafiolaire
hiéroglyphe	bétoglyphe	wéroglyphe	hiéroglyn	bétoglyn	hiéroslyphe	bétoslyphe
sanatorium	dénotorium	fanatorium	sanatoriuge	dénotoriuge	sanatosium	dénotosium
basilique	fuchilique	dasilique	basilin	fuchilinne	basinique	fuchinique
tabernacle	vosarnacle	dabernacle	tabernafle	vosarnafle	tabersacle	vosarsacle
écrevisse	aplevisse	icrevisse	écrevinne	aplevinne	écretisse	apletisse
alligator	obéfator	`elligator	alligatonne	obéfatonne	allimator	obéfajor
algorithme	ignorithm	`elgorithme	algorivme	ignorivm	algosithme	ignosithm
hippopotame	alérotame	éppopotame	hippopotase	alérotase	hippoporame	alléRoRame
davantage	rifantage	bavantage	davantam	rifantame	davanmage	rifanmage
cellophane	lapophane	chélophan	cellophase	lapophase	cellobane	lapobane
dinosaure	makosaure	tinosaure	dinozauffe	makosauffe	dinopaure	makopaure
camembert	lainembert	tamembert	camembef	lainembef	camemsert	lainemsert
missionnaire	sédionnaire	bissionnaire	missionnaitte	sédionnaitte	missiojaire	sédiojaire
aborigène	iménigene	`eborigène	aborigève	iménigève	aboritène	iménitène
noctambule	fasmambule	moctambule	noctambuse	fasmambuse	noctamsule	fasmamsule
lunatique	raisatique	runatique	lunative	raisative	lunarique	raisarique
sagittaire	vubittaire	chagittaire	sagittainne	vubitainne	sagigaire	vubigaire
hirondelle	afondelle	urondelle	hirondesse	afonchere	hironchelle	afonchelle
fontanelle	buranelle	sontanelle	fontanesse	buranesse	fontavelle	buravelle
fiduciaire	bélysiaire	viduciaire	fiduciainne	bélysiainne	fiduniaire	bélyniaire
auparavant	usaravant	ouparavant	auparatant	usaratant	aupatavant	usatavant
subjonctif	gasponctif	chubjonctif	subjonctil	gasponctil	subjoncmif	gasponcmif
mucosité	ralosité	nucosité	mucosiné	ralosiné	mucopité	ralopité
béchamel	fesamel	péchamel	béchamette	fesamette	béchavel	fésavel
hélicoptère	augusoptère	ilicoptère	hélicoptenne	augusoptenne	hélicopmère	augusopmère
somnifère	balsifère	chomnifère	somnifeque	baslzifeque	somnilère	balzilère
culinaire	sakinaire	pulinaire	culinaisse	sakinaisse	culicaire	sakicaire
chrysanthème	blésanthème	prysanthème	chrysanthèque	bésanthèque	chrysanvème	blésanvème
sédentaire	lèkantaire	fédentaire	sédentainne	lékantainne	sédengaire	lèkangaire
testicule	faussemicule	desticule	testicune	faussemicune	testivule	faussemivule
génocide	limucide	chénocide	génocif	limucif	génolide	limulide
congélateur	mandolateur	pongélateur	congélateuf	mandolateuf	congélagneur	mâdolagneur
farandole	soufandole	varandole	farandomme	soufandomme	faranchole	soufanchole
bastingage	rablingage	pastingage	bastinganne	rablinganne	bastinfage	rablinfage
lapalissade	minolissade	rapalissade	lapalissaffe	minolissaffe	lapalimade	minolimade