Phonological Variation and Inference in Lexical Access

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Recent experiments have indicated that lexical access in speech is highly tolerant of mismatch. An isolated sequence such as [wikib] strongly disrupts access to the underlying lexical entry (wicked). This observation seems inconsistent with the systematic variability found in the phonetic form of words. Two cross-modal priming experiments tested the hypothesis that phonologically regular variation is perceptually acceptable. Participants heard tokens like [wikib] embedded in contexts that either licensed the change as a result of a regular assimilation process (e.g., [wikib praŋk]) or rendered the change phonologically unviable (e.g., [wikib geim]). The tokens with contextually unviable deviations did not effectively access lexical representations. In contrast, the same tokens in viable phonological context primed as strongly as unchanged controls. These results suggest that mapping speech onto lexical representations involves on-line phonological inference.

The standard model of auditory lexical access assumes some kind of matching process between the perceptual input and a form-based lexical representation, through which access to syntax and semantics is gained. In recent years, increasing interest has been focused on the details of this matching process and in particular on the effect of mismatch on the system. Norris (1982), for example, argued that models of speech comprehension, when faced with mispronunciations such as “shigarette” for cigarette, should be able to select the correct lexical candidate despite the sensory mismatch. Indeed, one of the original arguments for the introduction of McClelland and Elman’s (1986) TRACE model was the ability of the network to cope with such mismatch. However, what is the evidence that human listeners can in fact process distorted words without difficulty?

It is certainly true that given time, listeners with incomplete sensory information can identify words. Salasoo and Pisoni (1985), for example, used forward and backward gating techniques to examine the interaction between sentential context cues and acoustic-phonetic information and found that often participants needed only partial sensory information to confidently identify words. However, this technique is an off-line task, which, as Salasoo and Pisoni pointed out, involves unusual stimuli. Therefore, it is plausible that their results do not reflect normal speech-processing mechanisms. In contrast, a number of recent studies using on-line priming techniques have indicated that the lexical-matching process is highly intolerant of deviation and that lexical access can be disrupted by mismatches as small as a single feature, irrespective of where this mismatch occurs in a word (Connine, Blasko, & Titone, 1993; Marslen-Wilson & Gaskell, 1992; Marslen-Wilson, Moss, & van Halen, in press; Marslen-Wilson & Zwitserlood, 1989).

Marslen-Wilson and Zwitserlood (1989) used cross-modal associative priming to study the effects of word-initial mismatch on lexical access. The experiments compared the priming effects of nonword rhyme primes with the effects of the source words (e.g., comparing noney—BEE with honey—BEE). They found that rhyme primes were always less effective than the source words in the facilitation of the target words and that only when the competitor environment of the source word was particularly sparse was there any significant facilitation by the rhyme prime. Subsequent research by Marslen-Wilson et al. (in press; see also Marslen-Wilson, van Halen, & Moss, 1988) showed that this failure of priming holds even for phonologically minimal mismatches, where the prime deviates by a single feature from its source word—as in the contrast between task–JOB and dask–JOB (although Connine et al., 1993, found some residual priming for tokens with single-feature deviations). Parallel experiments by Marslen-Wilson and Gaskell (1992) showed that a similar pattern occurs for word-final deviations. Even for trisyllabic words, small phonetic deviations (e.g., “apricod” for apricot) could still block cross-modal associative priming (e.g., of FRUIT).

These studies show that small deviations from the canonical pronunciation of a word always disrupt lexical access, as measured by cross-modal priming. In some cases, this reduction in priming is complete; in other cases, there remains residual priming. However, in all cases, a near perfect match between the speech stream and the lexical representations seems needed for word recognition to occur without disruption.

These findings seem difficult to reconcile with the appar-
ent noisiness and variability of the speech signal and especially with the widespread processes of phonological variation that change the phonetic form of words. If the matching process really is so intolerant of variation, then much natural variability in speech should cause mismatch, implying that listeners either fail to understand much of what is said to them or must use postperceptual recovery mechanisms to retrieve the original message. In the present research, we attempted to resolve this conflict, showing how phonological variation in surface form need not, in fact, be treated as mismatch.

**Phonological Variation**

Phonological variation is systematic variation occurring within conjunctions of sounds in speech. The type of variation we addressed in our experiments is known as place assimilation, which is an optional but very widespread process in normal connected speech (Barry, 1985). In English it occurs syllable finally, usually at a word boundary, when the previous consonant adopts the place of articulation of the following segment. The effect occurs for coronal segments (e.g., /t/ or /d/ or /n/) that are followed by noncoronals, such as labials (e.g., /p/, /b/, /m/) or velars (e.g., /k/, /g/, /n/). In a phrase such as /'wikid prsnk/ (wicked prank), the labial place of the /p/ can migrate to the previous consonant, meaning that the sequence can be phonetically realized as [wɪkb præŋk]. However, place assimilation in English is an asymmetric process, so that noncoronal segments cannot assimilate to following coronals (e.g., /blæk tə/ black tie, is not realized as [blaet tə]).

In fact, this depiction of assimilation is oversimplified. First, in the assimilation of stop consonants, the assimilated segment does not contain a burst because of the influence of the following burst. A more realistic representation of the aforementioned assimilation is [wɪkb^5præŋk] (LadeFoged, 1982).

Second, place assimilation is a more graded process than is suggested by the aforementioned description. Articulatory analyses of place assimilation (Barry, 1985; Kerswill, 1985; Nolan, 1992) have shown that place-assimilated segments can contain residual coronal information. For example, Nolan showed that for coronal to velar assimilations (e.g., /t/ → [k]), the resultant segment contains varying degrees of both coronal and velar place. Even when there is no residual acoustic evidence of coronal place, a hidden articulatory gesture may remain (Browman & Goldstein, 1990). In fact, Browman and Goldstein argued that such results support an account of place assimilation in which the degree of assimilation of a segment depends on the temporal overlap between the two place gestures. By this account, complete assimilation is just an extreme case where two gestures overlap to such an extent that one becomes acoustically hidden by the other.

Hayes (1992), however, argued that the facts of assimilation can also be accommodated by a model of assimilation incorporating both a phonetic coarticulatory element and a true phonological change. This standpoint is supported by the work of Holst and Nolan (1995), who showed that full assimilations within a single articulator (as in the movement of the tongue tip in /s/ to /ʃ/ assimilation) show no evidence of any blending or overlap, as would be predicted by a gestural overlap account of assimilation.

Our aim was to examine the effects of complete assimilation on the process of lexical access. When assimilation is complete, no acoustic cues to the underlying coronal place of articulation remain. Thus, in terms of their phonetic form, such assimilated segments are unambiguously noncoronal. However, to the perceptual system, they are ambiguous. A surface [k], for example, can be an assimilated token of /t/, or it can be just a simple /k/. This lexical ambiguity distinguishes complete assimilation from other coarticulatory changes that involve only partial phonetic change (e.g., Elman & McClelland, 1988; Mann & Repp, 1981; Martin & Bunnell, 1982; Repp, 1978, 1983).

The problem we needed to address is how the human speech-recognition mechanism can process phonologically variable speech when the matching process has such a low tolerance level for variation. Two separate issues emerge, one based on the phonological representation of lexical items and the other based on the mechanism by which speech sounds are evaluated.

We envisaged three possibilities for the lexical representation of phonologically variable speech. The standard assumption is that there is one fully specified phonological representation for each lexical item. However, it is also possible that phonological variation is dealt with by changing the properties of lexical representations, either by adding to the lexical representation to include variant forms (e.g., Harrington & Johnstone, 1987; Klatt, 1989) or by abstracting away from variation and eliminating redundant and unmarked aspects of the representation (Lahiri & Marslen-Wilson, 1991).

The second issue concerns the extent to which phonological inference is part of the access system. Models of lexical access often assume that the units of speech are assessed in isolation, but here we discuss the possibility that segments are analyzed in the context of phonological rules or constraints that specify the phonological contexts in which different assimilation processes can take place. These processes may operate either before the lexicon is accessed (Gaskell, Hare, & Marslen-Wilson, 1992; Massaro & Cohen, 1983; Pulman & Hepple, 1993) or during and after initial access.

It is easy to view these issues of lexical representation and inferential processing as mutually exclusive. A strong phonological inference component in a theory of lexical access eliminates the need for anything other than a single fully specified representation. Equally, a representational theory that encodes all possible variants of a word along with their validating contexts requires no more than a simple matching mechanism. However, there are reasonable intermediate positions: for example, using a representational theory to deal with variation within a word and using phonological inference to compensate for between-word variation. Next, we explore a number of permutations of the aforementioned
hypotheses, examining the predictions they make for the perception of place-assimilated speech.

The most elementary viewpoint is that words are fully specified in the lexicon and that no phonological inference is used in the process of lexical access. In other words, all variation is treated as noise by the perceptual system. For this hypothesis to accommodate the finding that small random variations cause mismatch with lexical forms, it must predict that much phonological variation will also disrupt lexical access. It is possible, however, that the experiments on which we have based our view of the matching process are unrepresentative. The priming studies reported above manipulated isolated words that were heard in quiet laboratory contexts. The kinds of deviations we were concerned with in this study occur in connected speech and especially in fluent conversational speech. Experiments on isolated words may capture only a subset of the properties of the speech-recognition system, and where phonological variation is concerned, it may be necessary to study larger units of speech. The same kind of experiment carried out within the context of an utterance or a discourse may yield quite different results. In fact, much of the earlier research on "mispronunciation detection" in connected speech has suggested that listeners often do not detect small (single-feature) changes in the speech input (e.g., Cole, 1973; Marslen-Wilson & Welsh, 1978). One of our motives for the present experiments was to test this explanation.

An example of a pure representational hypothesis derives from the phonological theory of radical underspecification (Archangeli, 1988). This theory states that only marked, nonredundant features are represented in a lexical entry. A marked feature is one that is not in the default state, whereas a nonredundant feature is one that cannot be established using context-sensitive redundancy rules. The application of these principles produces an extremely compact, structured lexicon containing only essential information. Implementing this theory for English place assimilation requires the assumption that the default place of articulation is coronal, so velar and labial places are specified in the lexicon, but coronal place is not (cf. Paradis & Prunet, 1991). The susceptibility of coronal segments to place assimilation can then be explained. A default rule gives unspecified segments the default (i.e., coronal) place of articulation:

\[
[ ] \rightarrow [+\text{coronal}]
\]

In addition, context-sensitive assimilation rules can give the same segments a labial or a velar place:

\[
[ ] \rightarrow [+\text{velar}] /\_#[+\text{velar}] \text{ or }
[ ] \rightarrow [+\text{labial}] /\_#[+\text{labial}]
\]

These rules state that the unspecified segment can gain a labial or a velar gesture, provided the following phonological context is appropriate. However, the assimilation process cannot occur for noncoronal segments because they are already specified for place.

Radical underspecification is most readily interpreted in the context of speech production as a hypothesis about the mapping from lexical entry to surface form (Keating, 1988). However, our research concerns the mapping in the opposite direction—retrieval of the correct lexical entry given the surface form. Lahiri and Marslen-Wilson (1991) developed an interpretation of underspecification in a perceptual context, arguing that mental representations of lexical form are underspecified along the lines laid down in phonological theory. These abstract representations are the targets of the lexical-access process, and a set of simple assumptions about the matching process allow phonologically regular changes in surface form to be interpreted without causing mismatch. In particular, Lahiri and Marslen-Wilson argued that apart from match and mismatch between the input and specified features in the lexicon, there is also lack of mismatch, in which the feature in the input is irrelevant because the lexical entry for that feature is unspecified.

This argument explains how listeners could have an intolerant lexical-access system but still allow phonological change. Changes caused by phonological processes alter unspecified features and therefore do not mismatch the lexical entry. However, other types of change, which alter features that are specified in the lexicon, will cause mismatch with the lexical representation. In principle, this representational approach to the problem of variation allows the perceptual system to cope with variation without resorting to rules of phonological inference.

Alternative views do not solve the problem of variation representationally but rather through the use of phonological inference processes, which allow regularly variable surface forms to be mapped onto fully specified representations of lexical form, where the feature coronal, for example, is specified along with all the other place features relevant to a given language. In the two-level phonological parser developed by Pulman and Hepple (1993), a set of inference rules mediate between surface strings and lexical representations. These rules instruct the system to map, for example, surface [b] onto underlying /d/ and /lb/ at the lexical level. The inference rules dictate, however, that the interpretation of surface [b] as underlying /d/ (e.g., "wickeb" as wicked) can go through only under the appropriate phonological conditions—in this case, where the following segment is also labial.

This inferential approach has also been explored using a connectionist model of speech perception (Gaskell, 1994; Gaskell et al., 1992). The connectionist model uses a simple recurrent network (Elman, 1990; Shillcock, Levy, & Chater, 1991; Shillcock, Lindsey, Levy, & Chater, 1992), which is trained to map from the surface (phonologically variant) form of speech to the underlying representation. The network's response to place assimilation is examined by altering the surface identities of 50% of the segments in viable context for assimilation (i.e., word-final coronal segments followed by labial or velar segments). The task of the network is to extract the underlying identity of each segment in the sequence by using a three-segment output

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1 This asymmetry may arise as a consequence of the structure of the articulatory system, in which coronal gestures are often obscured by noncoronal gestures (Browman & Goldstein, 1990).
window, allowing the network to use following context as well as preceding context in its evaluations. For most of the input, this is a simple autoassociation task, but for the assimilated segments, the network needs to compensate for assimilation in order to make a correct response. It accomplishes this task by compensating for assimilation only once the following context has been identified as viable for assimilation to occur. The network’s recurrent connections allow it to exploit the statistical regularities in the speech stream and thus to learn to identify the contextual conditions needed for assimilation to occur. The prediction based on this hypothesis is that the mismatching effect of a surface deviation depends crucially on its phonological context: If this licenses the change as a phonological neutralizing process, there is no inhibition of the underlying lexical entry.

Experimental Considerations

In our research, we attempted to answer a number of questions that arise from the issues discussed above. First, do minimal changes produce mismatch when presented embedded in a sentence? If the apparent conflict between phonological variation and intolerance of deviation is an artifact of single-word experiments, then phonological changes in the surface form of a word may either go undetected or simply be treated as noise, with other factors, such as contextual constraint, compensating for any resulting ambiguities. This view is implied in TRACE’s treatment of inputs such as “pleasant,” which the system treats as tokens of the source word pleasant (McClelland & Elman, 1986), and in the 1987 version of the cohort model (Marslen-Wilson, 1987). In TRACE, in fact, the absence of bottom-up inhibition means that there is no direct mechanism for mismatch to block lexical access (Marslen-Wilson & Gaskell, 1992).

The experiments we report are a refinement of earlier studies on mismatch in lexical access (Marslen-Wilson, 1993; Marslen-Wilson & Gaskell, 1992; Marslen-Wilson et al., in press; Marslen-Wilson & Zwitserlood, 1989). Here, we used cross-modal priming to examine the perceptual effects of single-feature word-final changes in sentential context. There are two aspects to the use of sentential context. First, its presence may change participants’ tolerance of mismatch relative to the single-word experiments, perhaps by a shift in decision criteria. Second, there will be some reduction in the strength of the phonetic cues for the changed segments, especially the word-final voiced and unvoiced stop consonants, which are not typically associated with release bursts. This change of phonetic cues may also contribute to a reduction in mismatch effects in context.

Our second aim was to assess the sensitivity of the lexical-access system to the phonological representation of words. The phonological changes used in our experiments could, in the appropriate context, occur naturally as a result of place assimilation. Thus, according to a pure representation account of variation based on underspecification theory, the changed features should be unspecified in the lexicon and cause no mismatch with lexical entries. Third, we wished to examine the extent to which phonological inference affects the perception of cross-boundary phonological phenomena. In particular, does the phonological viability of a feature change, as determined by its segmental following context, interact with the presence or the absence of mismatch effects in lexical access? Our experiments, therefore, compared sentences with phonologically viable alternations with sentences in which the same changes occurred in a context making assimilation unviable. The unviable contexts were created by switching the place of the following segment from labial to velar or vice versa. For the base word wicked, for example, a viable change would be [wikib praerjk] (wickib prank), where the places of articulation of the [b] and the [p] match. An unviable change would be [wikib geom] (wickib game), where the labial place of the [b] could not have spread from the following velar [g].

The experimental paradigm used to make these comparisons was that of cross-modal repetition priming. Participants were presented auditorily with sentences containing a prime word in either phonologically changed or unchanged form, and at the offset of the prime, the visual target was presented. The target was always the intact test prime (e.g., wicked), to which participants made a lexical-decision response. The experiments cited in the introduction used cross-modal semantic and associative priming. We chose to use repetition priming here for two reasons. The first is that cross-modal semantic priming in a sentence context is not, in our experience, a robust technique. The second, and perhaps related, reason is that the sentential context can interact in complex ways with responses to semantically or associatively related targets (e.g., Williams, 1988). These problems are avoided by the use of the more robust identity priming task.

This task has already proved sensitive to the lexical properties of speech. A series of experiments by Marslen-Wilson, Tyler, Waksler, and Older (1994) used cross-modal repetition priming to examine the morphological structure of English words. They found that visual targets preceded by phonologically related auditory primes (e.g., forty—FORT or bulletin—BULLET) were not facilitated when compared with unrelated control primes (e.g., pocket—FORT). In contrast, morphologically related (e.g., serenity—SERENE) and semantically related (e.g., idea—NOTION) pairs showed reliable priming effects. This finding suggests that cross-modal repetition priming reflects the activation of lexical representations but that it remains insensitive to lower level form-based similarities.

To allow us to evaluate the effects of following context as well as to examine the time course of possible effects, we conducted two experiments and an initial pretest of the stimuli. The first experiment presented the prime sentences with the speech following the offset of the prime word (i.e., including the phonological context) removed. This procedure allowed us to examine the effects of the deviations

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2 TRACE does incorporate some context-dependent evaluation in order to compensate for natural coarticulatory changes. This mechanism is examined in the General Discussion section.
before their viability could be assessed. The second experiment presented the whole of the prime sentences, allowing us to examine the effects of phonological context. In each case, the target was presented at the offset of the prime word.\(^3\) We begin by describing the materials, which were the same in all experiments.

**General Method and Materials**

The 48 test sentences used in the pretest (of which 42 were selected for the two main experiments) consisted of, on average, 14 words (range of 10–20) in which a prime word was embedded. We manipulated the sentences with respect to three factors. These factors were as follows: (a) the absence or the presence in the prime word of a word-final phonological change, which in the appropriate context could occur naturally as a result of place assimilation; (b) the viability of the phonological context for assimilation; and (c) the prime–target relationship (either identical or unrelated control).

For each test item, six sentences were constructed. The sentences all had a common beginning and then diverged at the prime word according to the test condition. An example of each type of sentence is shown in Table 1.

The prime words were all one or two syllables long and ended with a vowel followed by a coronal segment (/t/, /d/, /n/). For the phonologically changed primes, the place of the final consonant was changed from coronal to either labial (/p/, /b/, /m/) or velar (/k/, /g/, /n/), as would occur naturally in place assimilation. The result of this change was always a nonword. We manipulated the viability of the following context of the prime by following the prime word with a word whose initial segment was either labial or velar. For those sentences in which the place of articulation of the changed target and the following context matched (i.e., velar–velar or labial–labial), the context was phonologically viable. For the sentences in which the places did not match (i.e., velar–labial or labial–velar), the context was phonologically unviable for place assimilation. We used the following assimilation rules to create the viable changes:

\[
\begin{align*}
t &\rightarrow k/\_#g \\
&\rightarrow p/\_#(b, m) \\
d &\rightarrow b/\_#(p, m) \\
d &\rightarrow g/\_#k \\
n &\rightarrow m/\_#(p, b)
\end{align*}
\]

These combinations avoided the use of the same segment for both the mismatch and the phonological context (e.g., *sweek kiss*).

<table>
<thead>
<tr>
<th>Sentence type</th>
<th>Changed</th>
<th>Unchanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viable</td>
<td>lean bacon</td>
<td>lean bacon</td>
</tr>
<tr>
<td>Unviable</td>
<td>lean gammon</td>
<td>lean gammon</td>
</tr>
<tr>
<td>Control</td>
<td>brown loaves</td>
<td>brown loaves</td>
</tr>
</tbody>
</table>

**Table 1**

**Sample Prime Words With Phonological Context**

\(^3\) The positioning of the target facilitated comparison of results between the two experiments as well as with earlier studies using isolated words. However, in the second experiment, the target was actually presented before the following context of the phonological changes was known, implying that only the immediate effects of phonological viability on word activations would be picked up.

**Pretest**

The pretest was necessary to ensure that the speech tokens used in the priming experiments had the correct surface place of articulation and to check for confounding factors in the experimental design. Our aim was to use tokens of speech that fell at either end of the assimilation continuum. Thus, the tokens used in the unassimilated condition should have had an unambiguous coronal surface form, and the assimilated conditions should have used word-final tokens that were unambiguously labial or velar. To check whether the intended surface forms were actually present, we used a forced-choice phonetic decision task, in which the two alternatives were the unassimilated and assimilated surface
forms of the prime words. To ensure that participants' decisions were not influenced by the following contexts of the changes, the stimulus sentences were presented with all speech following the offset of the prime words spliced out.

There were two possible confounding factors that might have occurred in the production of the stimulus sentences. First, the greater articulatory ease of the viable context sentences (where the changed segments and their following context had the same place of articulation) might have altered the quality of the word-final segments in these conditions. Second, there was a possibility that speaker bias could have produced a difference in stimulus quality between conditions. The pretest allowed us to check whether either of these factors had affected the properties of the word-final segment of the prime.

The perceptual quality of the following context of the prime word was important in Experiment 2, particularly the place of articulation of the consonant directly following the word-final changes, as this determined their viability. However, because in a VCCV (vowel–consonant–consonant–vowel) context, CV place cues are generally richer and more reliable than VC place cues (Ohala, 1990; Repp, 1978), we assumed that the context segments were unambiguous and did not pretest them.

Method

Participants. We tested 48 participants from the Birkbeck College Speech and Language subject pool. All were native British English speakers with ages ranging from 18 to 45 years. The participants were mostly students at the University of London and were paid for their participation.

Design. In the pretest, we manipulated two independent variables: phonological change and sentence type (see Table 1). Participants were given a forced-choice test between the unchanged and the changed version of the prime word and were asked to rate the confidence of their responses using a 9-point scale ranging from 1 (not at all confident) to 9 (very confident). Thus, the dependent variables were the responses of the participants (changed or unchanged) and the confidence ratings (1–9).

In all, there were 6 versions of each of 48 test items. These 288 sentences were split into 4 test versions, each including 72 test items. This meant the control conditions for the test items doubled up with 2 of the test conditions within an experimental version, but as the control items had different prime words, any repetition effects were avoided.

Procedure. Participants were tested in groups of two to four, sitting in booths in a quiet room. The participants were given answer sheets on which, for each sentence, two versions of the final word (the prime word) were printed, one corresponding to the changed version of the word and the other corresponding to the unchanged version of the word. In addition, for each sentence, there was a confidence scale consisting of the numbers 1–9. The sentences were played from DAT tape through Beyer Dynamic 770 headphones to the participants. Each item consisted of a warning tone followed by 5–15 words of left context and the ambiguous word. The participants then had 3 s to indicate on the answer sheet the word that best matched the word they heard and to circle the number corresponding to how confident they were about their choice. They were instructed to vary their ratings from 1 for a complete guess to 9 for a certain response. The participants completed 10 practice sentences and then were given a break. The 72 test items were then presented. Each session lasted about 20 min.

Results and Discussion

Four participants did not complete the test because of faulty equipment, and their data were not used in the analysis. Of the remaining 44 participants, there were 12 participants each for Versions 1 and 2 and 10 each for Versions 3 and 4. Each participant produced two response measures for each item: a forced-choice response to the two possible interpretations of the prime word and a confidence rating. For the purposes of this analysis, a correct response was defined as a response that agreed with the intended pronunciation of the final word (whether as a word or a nonword). All participants produced responses that were at least 80% correct.

For each item in each condition, we calculated the mean percentage correct and the mean confidence rating across participants. After examining these values and the digitized speech, we excluded six items. The rejected items were ones in which low response rates or confidence ratings coincided with poor quality stimuli. The means and the standard deviations for each condition for the remaining data are displayed in Table 2.

We conducted 2 two-way analyses of variance (ANO-VAs), for items and participants, for both measures on the means of the 42 remaining items, with the variables of phonological change (2 levels) and sentence type (3 levels). There were no significant effects of either variable, indicat-

<table>
<thead>
<tr>
<th>Response measure</th>
<th>Changed</th>
<th>Unchanged</th>
</tr>
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<tbody>
<tr>
<td>% correct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>87.9</td>
<td>90.6</td>
</tr>
<tr>
<td>SD</td>
<td>13.3</td>
<td>16.7</td>
</tr>
<tr>
<td>Confidence rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>7.8</td>
<td>8.8</td>
</tr>
<tr>
<td>SD</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Note. Confidence ratings were measured on a 9-point scale ranging from 1 (not at all confident) to 9 (very confident).
ing that there were no systematic differences between the clarity of word-final consonants in the test materials.

A further analysis examined the variation in the results according to the manner of articulation of the word-final segment of the prime (nasal, voiced stop, or unvoiced stop). All three groups produced low error scores and high confidence ratings, although there were small differences between the groups. The unvoiced stops were the most clearly recognized in the analysis (95% correct, 8.3 confidence rating), followed by voiced stops (92% correct, 7.8 confidence rating) and nasal segments (88% correct, 7.9 confidence rating).

The results of the pretest showed, first, that the vast majority of word-final consonants, whether changed or unchanged, were produced as intended and perceived as such. The mean percentage of correct responses was 91%, and the mean confidence rating was 7.95. These results suggest that the surface places of articulation of the critical segments were reasonably unambiguous, meaning that in the appropriate contexts they would be treated as either unassimilated or fully assimilated. Second, there were no significant differences across conditions, ruling out any interpretation of the subsequent results in terms of confounds in the production of the stimuli.

**Experiment 1**

**Method**

**Participants.** We tested 36 paid participants from the Birkbeck College Speech and Language subject pool. They were in the age range of 18–45 years and were mostly students. None of them had participated in the pretest.

**Design and materials.** In Experiment 1, we presented the test sentences up to the offset of the prime word, making the phonological following contexts of the prime words unavailable to the participants. We used the 42 test items that performed satisfactorily in the pretest (see Appendix A). Because the viability of the phonological context could play no part in this experiment, we collapsed the design to three prime types per item, representing three levels of a single variable, prime type. Two conditions contained related primes: one with a word-final phonological change (e.g., where *learn* was followed by the visual target LEAN) and one in which the related prime was presented unchanged. These conditions were compared with a control condition in which the prime word was unrelated to the target (e.g., where *brown* was followed by LEAN). In 50% of the control sentences, a phonologically changed prime (e.g., *brown*) was used, and in the other 50%, the primes were intact.

We split the sentences into three test versions, with one sentence from each test item in each version. Test version was included as a variable in subsequent data analyses to reduce estimates of random error. In the participant analyses, this referred to the number of the test version to which each participant was assigned, whereas in the item analyses, it referred to the number of the item group sharing the same pattern of assignment of conditions to test versions (items were randomly assigned to these groups).

To reduce possible strategic effects, we interspersed 150 filler sentences with the test sentences. Of these filler sentences, 100 were accompanied by nonword visual targets, with two thirds following an intact prime and one third following a phonologically changed prime. In 14 of each of these subtypes, the primes and the nonword targets were related in form. The fillers for which there was a form link between the prime and the nonword target were designed to discourage participants from associating phonological relatedness with real word targets. The remaining 50 fillers (also with one third following changed primes and two thirds following intact primes) had unrelated real word targets, reducing the proportion of sentences with a strong prime-target relationship. We matched the fillers with the test sentences for sentence length and prime frequency.

In addition to the test sentences and fillers, there were 25 practice sentences and 10 dummy sentences, played after breaks in the test sequence to allow for settling in. Therefore, the total number of sentences in each test version was 227, with the proportion of related items being 25% of the pairs with real word targets.

To encourage the participants to attend to the auditory stimuli, we used a secondary recognition task at the end of the experimental sessions. This task used 10 filler sentences from the experiment and 10 sentences not present in the experiment. The task of the participants was to identify the sentences they had heard in the experiment.

**Procedure.** Each participant was tested on one of the three experimental versions, in groups of one to four. They were warned that they would be given a recognition test on the auditory stimuli after the main experiment but that they should not try to memorize the sentences. The lexical-decision experiment was then carried out in three blocks with breaks in between each block: first the 25 practice sentences were presented, followed by the experiment, which was divided into two blocks of 101 sentences. Each sentence was preceded by a warning tone and a short interval. At the offset of the prime word, the monitor in front of the participant displayed the target word for 200 ms, and the participant was required to press the *yes* button if the target was a word or the *no* button if it was not a word. The reaction time was measured from the offset of the prime. The response box was set up so that the participants always responded yes with their dominant hand. Once all participants had responded or the 3-s time-out was reached, there was a short interval, and the procedure was repeated. The test session lasted about 45 min.

At the end of the lexical-decision experiment, the participants were given a recognition sheet containing 20 sentences, 10 of which were filler sentences in the experiment. The participants were instructed to circle the numbers of any sentences that seemed familiar to them. There was no time limit in this part of the experiment, but most participants completed the task in 2–3 min.

**Results and Discussion**

Of the 36 participants, 5 had high error rates (over 20%) or high mean response times (over 750 ms), and their data were eliminated from subsequent analyses. An additional 16 individual response-time scores over 1,200 ms were also excluded. After these exclusions, the mean response times were 578 ms for the phonologically unchanged condition, 584 ms for the changed condition, and 648 ms for the unrelated control condition.\(^4\)

\(^4\) The response-time analyses were based on the midmean statistic, which is the arithmetic mean of the central 50% of the data. The values given are the means of the item and participant midmeans. We also carried out an analysis of the data using simple means, which yielded similar results (see Appendix B).
Because the control condition consisted of both phonologically unchanged and changed items, we carried out a preliminary analysis to test whether the phonological change in the control words was significant. The changed items (e.g., brown) provoked longer reaction times (654 ms vs. 644 ms for the unchanged items), but this difference was not significant in a one-way ANOVA, $F_{(2, 56)} = 1$. We also analyzed the results with the manner of articulation of the prime word-final segment as a variable, but we found no significant effects involving this variable. Therefore, the remaining analyses are presented collapsed across this variable.

We performed two-way participant and item ANOVAs on the data, with the variables prime type (unchanged-related, changed-related, or unrelated control) and version (the number of the test version in which the data were collected). The effect of prime type was significant, $F_{(2, 56)} = 48.3, p < .01$; $F_{(2, 78)} = 27.8, p < .01$, with Newman–Keuls comparisons showing both related conditions to be significantly different than the control condition ($p < .01$). The difference between phonologically changed-related and unchanged-related conditions was not significant. The interaction between version and prime type was also significant, $F_{(4, 56)} = 11.1, p < .01$; $F_{(4, 78)} = 3.78, p < .01$. This finding suggests that either participant groups were differentially affected by the prime type variable or there were differences between the three item groups used in the random assignment of conditions to experimental versions.

A two-way ANOVA on the mean error proportions revealed a significant effect of prime type, $F_{(2, 56)} = 8.8, p < .01$; $F_{(2, 78)} = 6.2, p < .01$. This finding showed that the control condition provoked more errors (11.3%) than both the unchanged (5.3%) and changed (4.9%) conditions.

In summary, Experiment 1 showed a strong priming effect for both changed and unchanged prime words, with little evidence of a mismatch effect for the distorted words. This result contradicted the findings of the experiments on single words but by itself was not enough to isolate the mechanisms involved in this effect. It could be that the small deviations used here were treated as noise in the matching process but were insufficient to disrupt access to lexical information. An alternative explanation would be that the word-final changes were treated as the initial segments of the following word and that the word-final segments were perceived as deleted. This interpretation would suggest that the perceived absence of a word-final consonant was tolerated because of the naturalness of word-final deletions in connected speech. However, these findings also conform with a representational account of variation, such as underspecification, because the phonological changes used were assumed to map onto underspecified elements in the lexicon. We attempted to resolve these issues in the second experiment, in which the effects of phonological viability on lexical access were assessed.

Experiment 2

In Experiment 2, the full prime sentences were presented, enabling the following context of the phonological changes to affect the matching process.

Method

Participants. Forty-six members of the Birkbeck College Speech and Language subject pool participated in this experiment. Of these members, 3 had taken part in the pretest, but because the pretest had been 6 months earlier, we assumed it would not affect their performance. They were paid for their participation.

Design. The design of Experiment 2 was the same as that of Experiment 1 except that because following context was expected to be influential in Experiment 2, the full six-condition design was used, as shown in Table 1. The independent variables were phonological change (unchanged vs. changed) and sentence type (related-viable vs. related-unviable vs. control). There were six experimental versions, each including one condition from every test item. As before, the experimental version was also included as a variable in the ANOVAs to reduce estimates of random error.

The prime words were presented embedded in full sentential context, such as “The house was full of fussy eaters. Sandra would only eat lean bacon.” The target word (in this case LEAN) was presented at the offset of the prime. The breakdown of the fillers used was the same as that for Experiment 1.

Procedure. The procedure was the same as that of Experiment 1 except that all sentences were presented in full. The target word was presented at the offset of the prime, which was now mid-sentence.

Results and Discussion

Of the 46 participants, 5 were excluded because of high error rates (over 20%) or high mean response times for the test items (over 800 ms). In addition, individual item response times over 1,200 ms were excluded from analysis. The item and participant midmeans were calculated along with the error rates and are summarized in Table 3.

The reaction times in Experiment 2 were slightly slower than those in Experiment 1, with the overall mean increasing from 607 ms in Experiment 1 to 642 ms in Experiment 2. This may reflect an increase in the processing load when participants were performing the lexical decision, due to the continuation of the auditory stimulus sentences in Experiment 2.

As in Experiment 1, we carried out a preliminary analysis using the manner of the word-final segment of the prime as a variable, but we found no significant effects. Therefore, we collapsed the results across this variable.

We performed three-way ANOVAs on the midmean response-time data using the independent variables of sentence type, phonological change, and version (the number of

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5 This cutoff point was higher than the value used for Experiment 1 (750 ms), reflecting the overall increase in response times between the two experiments.
the test version in which the data were collected). Significant main effects were found for both phonological change, $F_1(1, 35) = 6.93, p < .05; F_2(1, 36) = 10.89, p < .01,$ and sentence type, $F_1(2, 70) = 8.83, p < .01; F_2(2, 72) = 17.65, p < .01.$ Across conditions, participants responded more slowly to phonologically changed words than to unchange words (651 ms vs. 628 ms, respectively). The effect of sentence type indicated that the unrelated control items were responded to more slowly (661 ms) than both the viable context conditions (623 ms) and the unviable context conditions (636 ms). There was also a significant interaction between version and sentence type, $F_1(10, 70) = 7.67, p < .01; F_2(10, 72) = 2.18, p < .05,$ suggesting that either participant groups were differentially affected by the sentence type variable or that there were differences between the six item groups used in the random assignment of conditions to experimental versions. It is possible that differences in the proportions of prime-final nasals, voiced stops, and unvoiced stops assigned to each item group contributed to this effect.

What is most relevant here is whether the context of a prime affects the mismatching effect of a phonological change. The ANOVAs showed the interaction of phonological change and sentence type to be only marginal, $F_1(2, 70) = 2.64, p = .08; F_2(2, 72) = 2.45, p = .09.$ However, this analysis is not the most direct way of addressing the question. The variable labeled sentence type was an amalgamation of two variables, prime-target relatedness (i.e., test vs. control prime) and phonological context (viable vs. unviable). In an ANOVA on just the four related-prime conditions, using the variables phonological context and phonological change, the interaction was significant, $F_1(1, 35) = 4.70, p < .05; F_2(1, 36) = 5.17, p < .05.$ Post hoc comparisons using the Newman–Keuls statistic showed a significant effect of phonological change for related–unviable items in both item and participant analyses ($p < .05$). The difference between the viable and unviable phonologically changed conditions was marginally significant (Newman–Keuls, $p < .10$ for both participant and item analyses). An ANOVA on the mean error proportions in each category revealed no significant main effects or interactions.

The results of Experiment 2 highlight the important role of phonological processes in lexical access. Changed primes, when presented in viable context for assimilation, produced a strong cross-modal priming effect and showed no mismatch effect in comparison to unchanged tokens. The same primes presented in unviable context produced a reduction in priming of 40 ms.

To interpret these results as a product of the perceptual mechanism's sensitivity to phonological changes, we must first rule out a more simple explanation of the findings. The phonologically changed segments and their following contexts varied along three phonetic dimensions: place of articulation, manner of articulation, and voicing. Of these dimensions, differences in place of articulation were fully controlled, with viable changes and their following contexts sharing the same place of articulation and unviable changes mismatching the place of the following contexts. The differences in voicing and manner of articulation were more variable, although the viable changes all differed from their following contexts on at least one of these dimensions (i.e., the changed segment was never phonemically identical to its following context).

It is possible, therefore, that the difference in priming between the viable and unviable changes could be explained in terms of a phonetic masking effect of the context segments on the changed segments (Kallman & Massaro, 1979). Overall, the viable contexts may be more similar to the changed segments than are the unviable contexts and so may more effectively mask the mismatching effects of the phonological changes. Similarly, these effects could be the consequence of differential phonetic contrast effects between the viable and unviable conditions (Repp, 1978, 1983).

To examine these possibilities, the stimulus items were categorized according to the phonetic similarity between the changed segments and their viable and unviable contexts (in terms of the features place of articulation, voicing, and manner of articulation). The masking interpretation would predict that when the viable contexts are phonetically more similar to the changed segments than are the unviable contexts, the mismatching effect of the changed segments should be smaller, and therefore the difference between response times to the viable–changed and unviable–changed conditions should be greater. Twenty-two items had phonologically changed segments that were phonetically more similar to the viable following contexts than the unviable following contexts (e.g., the /m/ and the /b/ in the viable assimilation learn bacon differed only in manner, whereas the /m/ and the /g/ in the unviable assimilation learn...
gammon differed in both place of articulation and manner of articulation. In the remaining 20 items, the phonologically changed segment either was equally phonetically similar to both viable and unviable context segments (19 items) or was more similar to the unviable context (1 item).

An item ANOVA on these groups revealed no effect of phonetic similarity on the viability effects: The first group showed a 29-ms viability effect, and the second group showed a 28-ms viability effect, $F_1(1, 40) < 1$. A correlational analysis of these data showed a small and insignificant correlation in the opposite direction of the predictions of the masking or contrast hypotheses (Pearson’s $r = -0.03$, $p > .10$). We argue, therefore, that the effects found here are best described in terms of a context-sensitive inference process rather than a more low-level phonetic masking.

These results support the claim that the lexical-access process is intolerant of small deviations. The changes used in the unviable context conditions were all single-feature deviations, but they still produced a 40-ms mismatch effect. Given that these minimal deviations had such a strong effect on response times, it was relevant to ask whether there was any residual priming for the phonologically changed words in unviable context. In this experiment, we had two types of control words: changed and unchanged. Some studies cited in the introduction (e.g., Marslen-Wilson & Gaskell, 1992; Marslen-Wilson et al., in press) found no residual priming for phonologically changed words in cross-modal priming tasks, but these studies used a comparison to unchanged control words. If we make the same comparison here, there was again no apparent priming (test–control difference = 4 ms). This apparent lack of priming may be due to the influence of two competing factors, one being the actual priming due to the relatedness of prime and target and the other being inhibition or slowing simply because of encountering a nonword. For this reason, we took the phonologically changed control word to be the fairest baseline for assessing priming effects for changed words. When the reaction times for the changed–related words in unviable contexts were compared with the changed control words there was a suggestion of priming for the changed words in unviable context, with a marginally significant 24-ms effect (Newman–Keuls, $p > .10$ by participants; $p < .05$ by items).

General Discussion

The two experiments reported here provide evidence relating to a number of interconnected issues in the area of auditory lexical access: the mechanics and dynamics of lexical access and the effect of phonological processes on lexical access. Next, we discuss these issues in light of the new evidence our results provide.

Goodness of Fit in Auditory Lexical Access

One motive for our experiments was the finding that for isolated words, minimal distortion of the tokens of speech disrupted lexical access. Considering the unviable context conditions of the two experiments, the only difference between the sentences in these conditions was in the place of articulation of the word-final consonant of the prime word. In Experiment 1, with no following context this made no difference, but in Experiment 2, this deviation of a single phonetic feature was enough to disrupt the priming that was found by 40 ms. The results of Experiment 2 therefore provide strong evidence in favor of a lexical-matching process that needs an extremely good fit to activate lexical representations.

The presence of a mismatch effect confirms that the repetition-priming technique is sensitive to small changes in the speech signal and is therefore a valid tool for examining the process of lexical match. The absence of this effect in Experiment 1, where the sentences were cut at the offset of the prime word, therefore requires explanation, given the results of experiments on isolated words where mismatch effects were found for all distorted tokens. One possibility is that the additional processing load created by the preceding speech forces participants to process speech with increased tolerance for deviation. This is unlikely given the results of Experiment 2, where deviation did have an effect. We return to this question in the next section.

Turning to the dynamics of the mismatch effects, comparison of the two experiments implies that in Experiment 2 phonological context was brought into play very rapidly, in less time than it took for the participant to respond to the target word. This kind of result is difficult to model using the winner-takes-all architecture of models like TRACE (McClelland & Elman, 1986), because our results suggest that the winner takes nothing unless it meets a fairly stringent criterion. Where TRACE fails is that the only mechanism it has for reducing a word-node activation is by lateral inhibition from other active words. In this experiment, the deviation was word-final and inhibition only occurred later, when the context of the change was known. At that point, the base word would normally be dominant in terms of word-level activation and therefore fairly resistant to lateral inhibition. We argue that our results, if interpreted in TRACE-like terms, require direct inhibition from featural information, so that mismatching information can have strong effects in a short time.

Phonological Processes and Lexical Access

The most striking finding in this research is the strong effect of the phonological context of deviations found in Experiment 2. This pattern of results cannot be explained in terms of masking of the changed segment by its following context nor by a contrastive effect of phonetic similarity. Instead, it reflects a higher level process of phonological inference that resolves underlying ambiguity during word recognition. If this result is to be accommodated into the standard paradigm of lexical access, the definition of a mismatch must be revised.

When sentences were presented with a changed prime in a context in which the change was phonologically viable, there was no mismatch effect—the target was facilitated as
strongly as it was for the unchanged primes. However, the same change in circumstances where it could not occur naturally strongly reduced the priming effect. A matching process that analyzes segments or features without reference to their neighbors cannot cope with these results. Neither the changed segments nor the context segments by themselves create mismatch; only when the two elements combine does mismatch occur.

We can now offer an explanation for the absence of a mismatch effect for changed words in Experiment 1, which contrasts with the earlier results using isolated words. At the point where the sentences were cut off, the word-final deviation had been presented, but the following context was unknown. The preceding sentential context means that the participants had engaged the processes normally involved in the interpretation of connected speech. Within the framework of this type of analysis, the underlying identity of the word-final deviation in the prime word is ambiguous. If the deviation is in fact underlying coronal, it should not mismatch the lexical entry for the word, but if it is underlying noncoronal, it should cause mismatch. This ambiguity can be resolved only once the following context of the changed segment is known. Thus, a matching process that is intolerant of mismatch but at the same time acts conservatively, only rejecting candidates when there is unambiguous mismatching information, would predict precisely the results found in our experiments: No mismatch in Experiment 1, where the phonological viability of the change was unknown, but a strong mismatch effect in Experiment 2, where a minimal but unambiguous mismatch was perceived.

Modeling Variation in Lexical Access

We now turn to the implications of these results for psychological models of auditory lexical access. The relevant theoretical alternatives for the resolution of surface variation in speech perception can be split into the three categories defined in the introduction: models treating variation as noise, those dealing with variation in the lexical representation, and those compensating for variation by phonological inference. We briefly review these approaches, with emphasis on the predictions for cross-boundary variation such as assimilation.

The traditional approach to variation has been to treat it as noise. Thus, the only way for phonologically modified words to produce sufficient match in this type of model is either to tolerate small mismatches or to allow top-down influences to combine with the sensory input. It is clear that this approach is untenable, because our research has shown that the same deviations can cause mismatch or be processed fluently, depending on their following context.

Lexical approaches deal with variation either by adding to the lexical entry of a word to cope with the different variants of a word or by reducing the lexical entry to more abstract, invariant features. An example of the latter approach is the underspecification theory, applied to lexical access by Lahiri and Marslen-Wilson (1991).

This approach predicted that the changes we used would not create mismatch because they were mapping onto coronal segments in the lexicon that were unspecified for place of articulation. Experiment 1, where the phonological context of the changes was unknown, supports this prediction because no mismatch effect was found, but the results of the second experiment are more difficult to handle. The application of a simple processing strategy to an underspecified lexicon would predict that the deviations used should not mismatch, regardless of the following context. Clearly, abstraction from variation is not enough here: There must be some phonological inferencing process in lexical access, occurring either lexically or prelexically. A lexical phonological inference mechanism would be compatible with the underspecified representations hypothesized here. The underspecified lexicon allows phonological variants to map onto the lexicon, and cross-boundary lexical rules are then applied to assess the viability of the change as its context is perceived.

However, what of the purely inferential approach described in the introduction? Using this approach, we need only assume a single fully specified representation of a word in the lexicon onto which variable speech is mapped. The best known example of this kind of model is the TRACE network of McClelland and Elman (1986). Their model consists of an interactive activation and competition network organized into three levels of representation: the feature, phoneme, and word levels. Within each level, elements are represented locally by a single node that is connected through inhibitory links to all other nodes in that level. The nodes are connected to nodes in other levels by facilitatory links. Regular variation in the input is dealt with in two ways. First, active phoneme units can alter the feature to phoneme connections for adjacent input to compensate for coarticulatory effects (Elman & McClelland, 1986). Second, top-down activation from word to phoneme level biases the activations of the phoneme nodes in favor of phonemes forming part of currently active words. Elman and McClelland (1988) argued that this structure was able to model the lexical and sublexical effects of compensation for coarticulation found in phoneme categorization experiments.

However, the type of variation we were looking at here has a number of properties that cause problems for the mechanism outlined above. Consider the behavior of a TRACE model when a place-assimilated sentence is being processed. Again, there would be a lexical effect on the activations of relevant phoneme candidates. For example, given the input [swik], there would be activation of the /d/ node due to top-down facilitation by the word sweet. Therefore, TRACE would have no trouble recovering from the deviation found in Experiment 1, where there was no following context and no mismatch effect was found. However, the problem occurs when an attempt is made to simulate the mismatching effect of unviable context in Experiment 2.

TRACE deals with contextual dependencies such as coarticulatory change by hard wiring links between the relevant phoneme and feature nodes. Although TRACE has not
been set up to compensate for neutralizing variation such as place assimilation, one would imagine that a similar method could be used in this case. That is, the activation of phoneme nodes such as /p/ or /k/ (which could form the following context of a place-assimilated phoneme) would lead to weighting changes between the preceding feature and phoneme nodes. These weight changes would make the network more likely to activate a coronal segment when presented with a velar or a labial segment. For example, when presented with the input [swik gsl] (underlyingly, sweet girl), activation of the /g/ node would modify the links between the preceding feature and phoneme nodes, facilitating a /l/ response to the surface [k]. If these links were powerful enough, TRACE might show effects of viability of phonological context at the phoneme level. However, this contrast would not translate to a strong difference in activations at the word level. Both viable and uviable phonologically changed conditions would leave the base word strongly activated and therefore would minimize the mismatching effect of the uviable phonological change. Because cross-modal priming reflects activations at the word level, this finding implies that the viability effects found here cannot be accommodated by TRACE. 

In contrast, the connectionist model described in the introduction (Gaskell, 1994; Gaskell et al., 1992) displays a strong effect of viability of context, because it learns to associate the noncoronal place of an assimilated segment with the same place in the following context. Therefore, the results of Experiment 2 are easy to explain using this approach. However, the model fares less well when the results of Experiment 1 are considered. In our simulations, any deviation from an autoassociative mapping (i.e., any assimilated input) was relatively rare, constituting less than 1% of the input corpus. Because of the dominance of an autoassociative mapping, the network would not compensate for assimilation until the following context was known to be viable. Therefore, the model would predict that in Experiment 1, where the primes were presented with no following context, there would be a mismatch effect for the changed primes.

It seems that both purely representational and purely inferential models have trouble accommodating our findings. Although the research is at too early a stage to rule out a prelexical inferential account, maybe the most parsimonious account is that within a word or a morpheme, phonological variation is accommodated by a process of lexical abstraction, but across word or morpheme boundaries, phonological inference processes act to compensate for the change. This hybrid approach thus combines the simplicity and the cognitive economy of the representational account with the flexibility of the inferential account. We are also optimistic that current research using recurrent connectionist architectures will lead to a single mechanism that can explain how abstract representations are developed in a context-dependent processing environment (Gaskell, Hare, & Marslen-Wilson, in press; Gaskell & Marslen-Wilson, 1994).

References


Appendix A

Stimulus Sentences

The format for each of the items in the following list of stimulus materials is: word-final segment (unchanged/changed), preceding context, PRIME, viable following context/unviable following context/control PRIME, and following context.

1. d/b I don't see how we can miss it. The field has a broad path across it/gate at one end/WOOD right next to it.
2. d/b The conditions were changing. After a few minutes the CLOUD melted away/grew larger/FLOOD started to subside.
3. d/g I wouldn't bet my life on Chelsea winning. They CONCEDE penalties all the time/goals all the time/DIVIDE their midfield too much.
4. d/b The attraction of the game was the price. After all, the CROWD paid just two pounds to enter/got in free of charge/
5. d/b Finally the starter arrived. It turned out to be a HORD mixture of celery and tomato/cauliflower salad/SALAD with French dressing.
6. d/g There's little point trying to cover up. I think I will PLEAD manslaughter/guilty/GUIDE the press towards the story.
7. d/g I would say you got what you deserved. That was a WICKED prank/game/VALID sentence.
8. d/g I was soon almost overcome with nostalgia. The BAL-LAD kept bringing back the memories/brought tears to my eyes/CHILDHOOD visions all came back.
9. d/g Don't take any chances on the summit. I think you BLEED copiously at high altitude/more at high altitude/SLIDE easily up there.
10. d/g It all looked suspicious. There was a note hidden under the BREAD counter/board/SHED door.
11. d/g I feel like I'm going to burst. I've got to CONFIDE Karen's secret to someone/my secret to someone/AVOID seeing Clare until tonight.
12. d/g You won't get very far with that. These days a QUID can hardly carry a cup of tea/buys you next to nothing/ROD needs live bait to catch the big fish.
13. d/g What about your daily travel? Do you RESIDE close to the centre/more than a mile from the centre/REGARD the bus system as adequate.
14. n/m The kitchen looks more like a bomb site. We got the BASIN plastered with rubbish/coated with rubbish/BROKEN chairs out of the room.
15. n/m Intent on making a good impression, Terry took a CLEAN pullover from the drawer/gown from the wardrobe/FAWN tie out of the wardrobe.
16. n/m They had done this routine so many times. First the CLOWN pretended to faint/called for a volunteer/HORN would hoot twice.
17. n/m As they watched from their hideout in the marsh, the CRANE picked up a large twig/gripped a twig with its claws/STONE fell off the cliff and into the nest.
18. n/m For months we felt lost without Felix. He was a DIVINE person/creature/GOLDEN example to us all.
19. n/m We inspected the postmark. It looked like a FOREIGN postcard/card/GERMAN letter.
20. n/m As it was the middle of the wet season, the GRAIN became mouldy in just three weeks/came at the wrong time for the villagers/TAN didn't have time to develop.
21. n/m At four o'clock the lesson began. The teacher took a GREEN book from the shelf/cookery book from the shelf/PEN out of his drawer.
22. n/m We have a house full of fussy eaters. Sandra will only eat LEAN bacon/gammon/BROWN loaves.
23. n/m Alison ran around the garden. She was pretending to be a MARTIAN pilot/girl/ MOUNTAIN explorer.
24. n/m It's hard to get any peace in this village. The PARSON pesters us all the time/comes round all the time/MILKMAN wakes us up at six in the morning.
25. n/m The kitchen was very well looked after. Along one wall stood a PINE bench/cupboard/FINE sideboard.
26. n/m Sue didn't remain upset for long. The PUN brought a wry look to her face/crept into her mind as she read the paper/TUNE helped to pick her up.
27. n/m We can't use the stove tonight, the PYLON broke in the wind last night/cracked in the wind last night/ROTTEN thing's gone wrong again.
28. n/m We won't have enough time to see it. I think the QUEEN broadcasts at three/catches the plane at three/PLANE takes off at two.
29. n/m I don't think you'll make it in time, the TRAIN bypasses Royston/gets in at four/PLANE is to leave at five.
30. t/k We finally came to a halt at six. The BOAT grounded in the thick mud/beached in the thick mud/SKIRT of the hovercraft was punctured.
31. t/k What is the current rate? I want to CONVERT Greek to British currency/British to Greek currency/BUDGET for my holiday abroad.
32. t/k Some areas weren't affected for a while. The DROUGHT gradually spread to the south/mainly affected the south/CHART showed that the South would be alright.
33. t/k The animals were all very different. The GOAT grew up so quickly/behaved like a clown/FAT one just sat around all day.
34. t/k I think they were well received. They were asked to give a REPEAT golf/display/performance/CONCERT in New York.
35. t/k Are you sure about the wine? I think TROUT goes with something lighter/belongs with something lighter/FRUIT salad needs something lighter.
36. t/p I'd know that face anywhere. I've always had an ACUTE memory for faces/camera-like memory/EXPERT knowledge in this area.
37. t/p I don't know how I remained sane. I used to COMMUTE by train/quite frequently/FORGET all my appointments.
38. t/p Everyone brought something along. Andrew made a lovely DATE bake/concoction/STOUT ale.
39. t/p The afternoon was a disaster. Philip thought the KITE belonged to him/caught the branches of a tree/SKATE must have been left at the rink.
40. t/p The magician called for silence. The PLATE began to roll across the table/glimmered in the darkness/SWEAT glistened on her forehead.
41. t/p At first everything went smoothly but unfortunately the TART burned in the oven/collapsed in the oven/VOTE went the wrong way. A
42. t/p I think it's early closing day today. You'll have to TROT back to the shops before four/quickly if you want to get there in time/WAIT until tomorrow.

A1 Tarp is not a word in British English.
Appendix B
Supplementary Analyses

We carried out the analyses of response times reported in the Results and Discussion section of Experiment 1 and Experiment 2 by using item and participant midmeans, calculated by taking the arithmetic mean of the middle 50% of the data. For comparison, given the concerns raised in research by Ratcliff (1993) and others, we summarize here the ANOVAs using the standard mean statistic. These analyses show the same pattern of effects as the midmeans analyses.

Experiment 1

The mean response time for the unchanged condition was 591 ms, compared with 603 ms for the changed condition and 662 ms for the unrelated control condition. An ANOVA showed the effect of prime type was significant, $F_1(2, 56) = 44.5, p < .01; F_2(2, 78) = 27.5, p < .01$.

Experiment 2

For the phonologically unchanged conditions, the mean response times were 639 ms for the viable condition, 628 ms for the unviable condition, and 668 ms for the control condition. For the phonologically changed conditions, the mean response times were 637 ms for the viable condition, 670 ms for the unviable condition, and 694 ms for the control condition.

Three-way ANOVAs showed significant main effects of phonological change, $F_1(1, 35) = 6.41, p < .05; F_2(1, 36) = 9.78, p < .01$, and sentence type, $F_1(2, 70) = 11.0, p < .01; F_2(2, 72) = 17.0, p < .01$, and a marginal interaction between these variables, $F_1(2, 70) = 3.67, p < .05; F_2(2, 72) = 2.67, p = .075$. Analysis of the four related conditions using the variables phonological context and phonological change showed a significant interaction, $F_1(1, 35) = 6.91, p < .05; F_2(1, 36) = 6.39, p < .05$.