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Height Differences in English Dialects: Consequences for Processing and Representation

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Key words

abstraction

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Abstract

This study examines the role of abstractness during the activation of a lexical representation. Abstractness and conflict are directly modeled in our approach by invoking lexical representations in terms of contrastive phonological features. In two priming experiments with English nouns differing only in vowel height of their stem vowels (e.g., *pin* vs. *pan*), we compare a conflict versus non-conflict situation across English dialects. Based on differences in the vowel height representation, the conflict occurs in American English, but not in New Zealand English. The results show that there is a lack of priming in the conflict, but not in the non-conflict situation. This is taken as evidence for the claim that lexical access is sensitive to conflicts and non-conflicts between acoustic-phonetic and phonological information. We therefore conclude that discrete phonological features are crucial determiners for successful speech perception, which is in line with abstractionist approaches.

1 Introduction

Speech perception models try to account for the mapping of continuous, physical acoustic speech events onto concrete, categorical representations in the mental lexicon (cf., Klatt, 1989; Miller & Eimas, 1995). This mapping mechanism must be able to deal with (or to provide an account of) the wide range of variation in the speech signal (cf., Lindblom, 1990), within and across speakers, social groups and dialects. From a

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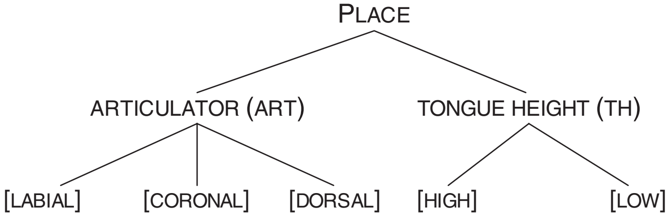
Figure 1

Organization of the articulator place and tongue height features (extract of the original feature tree in Lahiri & Reetz, 2002). Note that ARTICULATOR and TONGUE HEIGHT are independent. Crucially, TONGUE HEIGHT is not dependent on DORSAL (i.e., on ARTICULATOR)



theoretical linguistic perspective, the mapping and transformation process is located “somewhere” at the phonetics–phonology interface or even represents this interface (cf., Scobbie, 2007, for a detailed discussion of the topic).

Among several possibilities of resolving variation during lexical access and modeling lexical representations, ranging from sparse and abstract to detailed and exemplar-like (e.g., Bybee, 2001a; Goldinger, 1996a, 1998; Johnson, 1997; Pierrehumbert, 2001, 2002; Pisoni, 1993, 1997), we want to opt for an abstractionist view on the phonological side of the spectrum of possible models. We propose a Featurally Underspecified Lexicon account (FUL: Lahiri & Reetz, 2002) where lexical items consist of sets of phonological features. Vowels and consonants are described by the same set of features, similar to Clements (1985, 1989), except that there is no difference between vocalic and consonantal tiers. The relevant feature organization is represented in the (partial) tree in Figure 1 and follows Clements (1985) in some respects.

In contrast to Halle, Vaux, and Wolfe (2000, p.389), who group [DORSAL] together with [HIGH] and [LOW] under TONGUE BODY, we assume that the PLACE node dominates ARTICULATOR, TONGUE HEIGHT and TONGUE ROOT. The goal of this is to ensure complete independence between the articulator place features [LABIAL], [CORONAL] and [DORSAL] vs. the aperture or height feature [HIGH] and [LOW].

Thus, there is no dominance relationship between ARTICULATOR and TONGUE HEIGHT features. In other words, the height features are *not* dominated by DORSAL or any other ARTICULATOR variant such as BACK, as is the case in other feature geometry approaches. Therefore, height features can be specified independently of articulator features. Since the features are available for both vowels and consonants, it is thus possible to have non-dorsal high vowels (e.g., /ɪ/) or consonants (e.g., /ʃ/). The latter palato-alveolar fricative differs from its alveolar correspondent by the relative tongue height. Note that this height is not necessarily defined with respect to the back of the tongue: In this case, /ʃ/ is high since the tongue blade and the tip of the tongue are high in the oral cavity, relative to /s/, which is non-high.

In this article, we want to focus on the lexical access of vowels and will therefore introduce further characteristics of the model on the basis of vowel features. We first describe the articulator features which model the traditional distinction between front and back vowels. Front vowels are coronal (e.g., /ɛ/, /ɪ/), while back vowels are dorsal (e.g., /ɔ/, /ɒ/). Additionally, the articulator feature [LABIAL] sets apart round vowels from non-rounded ones (e.g., /y/ vs. /ɪ/). Next, tongue height features describe high (e.g., /ɪ/) and low vowels (e.g., /æ/). Mid vowels have no specification, that is, are neither low nor high (e.g., /ɛ/). In our notational system, the height feature for mid vowels is represented by a dash in empty square brackets ([–]). The non-specification of mid vowels is different from the assumed underspecification of [CORONAL] for front vowels, since the former is the consequence of a binary distinction between high versus non-high and non-low versus low, respectively. In a system with a three-way height distinction, the minimum of height features is two, high and low. High and low vowels are distinguished by the corresponding features [HIGH] and [LOW]. Mid vowels are neither high nor low.

Coronal underspecification, on the other hand, is a basic tenet of FUL and is rooted in underspecification theory (Archangeli, 1988; Kiparsky, 1985; Steriade, 1995), although the notion of underspecification in FUL differs in crucial aspects from the "traditional" views. First, it is assumed that underspecification of coronal holds universally. FUL assumes that all languages have a PLACE contrast, where CORONAL is underspecified and contrasts with the specified feature which is usually LABIAL OR DORSAL. Second, feature values are monovalent. Features are either specified or absent altogether. Finally, the phonetic output in speech production has always an articulator specification, while tongue height specifications for mid vowels may be lacking. Phonetic outputs are subsequently implemented by articulatory gestures (cf., Scharinger, 2009). Crucially, the non-specification of a feature may be as informative as the specification of another one.

Apart from the representational perspective, FUL offers an account of lexical access which is based on the feature structure of speech segments in the phonological and phonetic realm. It is crucial to bear in mind that we assume feature structure both in the phonological as well as in the phonetic module (and perhaps, we may even blur modular distinctions thereby, cf., Scobbie, 2007). As described in more detail in research on the computational aspects of the model (Reetz, 1998, 1999, 2000), the continuous and acoustically very fine-grained speech signal is first translated into an array of surface features. These features are extracted from the speech input on the basis of rough spectral properties. For instance, [HIGH] is extracted if the first formant of a vowel is below a certain frequency threshold. The extraction process should lead to a limited set of surface features and be constant across languages, although we are aware that not every feature can rely on the same acoustic cue or cues in all languages. We cannot pursue the important issue of cross-linguistic cue trading in more detail here, but we expect the primary cues for vowel height and place of articulation to be fairly consistent (cf., Stevens, 1998). The acoustic-phonetic main cue for the former dimension is the first formant value.

The phonetic surface features are then directly mapped onto their corresponding lexical representations. During this process, it is important that the feature specifications do not mismatch. A mismatch arises, for instance, if the feature [HIGH], extracted from the signal, conflicts with [LOW] in the lexical specification. That means that a high vowel /ɪ/ cannot access and activate the low vowel /æ/. On the other hand, if nothing is specified in the lexicon, then [HIGH] or [LOW] can be mapped onto the unspecified segment without a conflict (nomismatch). Similarly, if there is no feature extracted from the signal but the corresponding feature in the lexicon is high or low, a nomismatch arises. A match, finally, occurs if the feature extracted from the signal and the feature of the corresponding segment in the lexicon are identical. Note that there is a difference in signal feature extraction between place of articulation and tongue height, that is, regarding coronal and mid vowels. This has to do with the assumption that underspecification of coronal vowels is qualitatively different from the underspecification of mid vowels. Since all vowels must have a place of articulation, the feature [CORONAL] is always extracted from front vowels, even though these vowels lack a lexical specification [CORONAL]. On the other hand, tongue height features are never extracted from a vowel which is neither high nor low. In a way, then, there is also phonetic underspecification (Keating, 1988), in case the non-specification of vowel height is informative.[1]

The advantage of FUL is that it readily permits to make model-theoretical predictions about the process of lexical access. In this respect, the model has achieved accumulating support from behavioral and neurolinguistic experiments.

Using a semantic priming technique, Lahiri and Reetz (2002) found asymmetric activation of German labial and coronal nasals. In the traditional cross-modal semantic priming task (Tabossi, 1996) subjects are presented specific words on a screen. Shortly before the word presentation, they hear another word over headphones (the prime). This word has usually a semantic relationship to the word on the screen (the target). Subjects are required to provide lexical decisions (i.e., word or non-word responses) to the target. The amount of priming is then determined as the difference in lexical decision time between the semantic condition, where prime and target have a semantic relation, and the control condition, where the target is preceded by a semantically unrelated prime. Lahiri and Reetz (2002) presented German nouns minimally differing from existing nouns in the word-final nasal as primes. For instance, a prime was BAHM (from *Bahn* 'rail'), and a subsequent target was ZUG ('train'). Compared to a control condition, BAHM was as effective a prime for ZUG as for BAHN, but in another condition, BAUN (from *Baum* 'tree') did not prime STRAUCH ('bush'). Lahiri and Reetz (2002) interpreted these findings as follows: BAHM was an acceptable variant for BAHN since the word-final nasal [m] did not mismatch in place of articulation with the coronal (alveolar) [n], underspecified for its articulator feature. However, vice versa, the prime BAUN with alveolar [n] was a mismatch for the labial [m] in BAUM, since coronality was extracted from [n] and conflicted with labial [m] in the lexicon.

In the neurolinguistic realm, the work of Lahiri and her colleagues showed that automatic mismatch detection (MMN: Eulitz & Lahiri, 2004) as well as lexical access as measured by the P350 component of ERPs are also sensitive to feature mismatches versus nomismatches (Friedrich, 2005; Friedrich, Lahiri, & Eulitz, 2008). In fragment priming studies, they showed that an initial consonantal mismatch of coronal versus dorsal in DREN preceding GRENZE ('frontier') led to a reduced P350 response

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[1] Note that feature models (cf., Ghini, 2001) generally treat [LABIAL], [CORONAL] and [DORSAL] as monovalent features: There are no negative specifications such as [-CORONAL]. This differs from vowel height features which can differentiate between [-LOW] and [-HIGH] vowels if there is a four-way distinction. In our model, a four-way height distinction would be modeled by reference to other features, but it is beyond the scope of this article to discuss the issue in more detail.

in comparison to the priming of DROGE ('drug') by the fragment GRO, where no mismatch between prime and target occurred.

While the studies briefly reviewed above were concerned with featural mismatches versus nomismatches in the dimension of place of articulation, we were interested in vowel height features and their possible oppositions in lexical access. We furthermore wanted to avoid using non-words as primes for a behavioral task and therefore decided on a cross-dialectal comparison of vowel height in lexical decision, as measured by semantic priming.

Research in cross-linguistic perception of speech sounds has repeatedly shown that identical acoustic stimuli are processed differently depending on the listener's native language or dialect (cf., Conrey, Potts, & Niedzielski, 2005; Dufour, Nguyen, & Frauenfelder, 2007; Pallier, Christoph, & Mehler, 1997; Pallier, Colomé, & Sebastián-Gallés, 2001). It has been suggested that such findings are due to a perceptual reorganization of contrasts while listening to non-native sounds (Best, McRoberts, & Goodell, 2001; Best, McRoberts, & Sithole, 1988; Flege, Munro, & Fox, 1994; Meador, Flege, & MacKay, 2000). We entertain the hypothesis that processing differences between languages and dialects have to do with different feature oppositions during lexical access, ultimately going back to differing lexical representations of possibly one and the same lemma.

Two dialects allowing for the comparisons we were interested in are New Zealand English (NZE)[2] and American English (AE).[3] There, we find differences in the specification of vowel height in the short front monophthongal vowels, such that the same lemma with the meaning "cooking device" surfaces as [pæn] (with a low front vowel) in AE and as [pɛn] (with a mid front vowel) in NZE. For the sake of comparison with previous studies on NZE, we try to refer to this and further vowels by *lexical sets*, if no further phonetic specification is of importance (cf., Haggo, 1984; Hawkins, 1973; Kelly, 1966; Wells, 1982a, 1982b). The vowel in *pan* is referred to as TRAP vowel, while the vowel in *pen* is referred to as DRESS vowel and the vowel in *pin* as KIT vowel (cf., Bell & Kuiper, 2000). The peculiarities of the NZE as compared to the AE vowels are illustrated in more detail in the next section.

2 Short front vowels in New Zealand English and American English

The short front monophthongal vowels of NZE are known for their distinctive properties. Compared to AE, the realization of the TRAP and DRESS vowel is higher (closer). Thus, the TRAP vowel in NZE rather corresponds to a mid vowel (for which we provide the label /ɛ/), while the DRESS vowel is closer to a high vowel (labeled as /ɪ/). Finally,

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[2] "New Zealand English" refers to the English spoken in New Zealand and is considered to be a homogeneous dialect outside Southland (Bauer, 1986, p.227).

[3] The notion "American English" is not used in a sense subsuming all North American dialects. It refers to the English spoken in New England and lacks processes such as the Northern Cities Shift or the /æ/–/ɛ/-reversal (cf., Labov, Ash, & Boberg, 2006), that is, has a three-way height contrast for (short) front vowels.

Table 1
Comparison of the pronunciation of short front vowels in NZE versus AE

Lexical set	*Pronunciation NZE*	*Pronunciation AE*
TRAP	[ɛ]	[æ]
DRESS	[ɪ]	[ɛ]
KIT	[ə]	[ɪ]

the KIT vowel in NZE is realized as a more central and lower vowel, compared to AE (cf., Bell & Kuiper, 2000; Gordon, Maclagan, Hay, Campbell, & Trudgill, 2004; Maclagan & Gordon, 2004; Maclagan & Hay, 2004). For the latter vowel, we use the label [ə]. A sample of the vowel differences is given in Table 1. Note that the transcriptions are averaged approximations. Individuals (such as older speakers) may still have pronunciations closer to British English or American English or adapt their pronunciations, depending on the social context (cf., Hay, Nolan, & Drager, 2006; Langstrof, 2003, 2006).

The vowel change in NZE is well documented. For instance, Bauer (1986) and Bell (1997) provide extensive auditory evidence. There are also detailed acoustic analyses (e.g., Watson, Harrington, & Evans, 1998; Watson, Maclagan, & Harrington, 2000) which show that the phonetic realizations of the NZE short front vowels significantly differ from those of British English or American English speakers. The changes in the NZE vowel system are considered to be the result of a chain shift, which started with the raising of the TRAP vowel (Maclagan & Hay, 2004), in turn affecting the locations of the DRESS and KIT vowels in the vowel space.

The advantages of the differences between the NZE and AE short front vowels for testing the access hypotheses of FUL regarding vowel height are as follows:

The TRAP vowel in NZE appears to have a different lexical representation than in AE. This difference can be expressed by the absence of the feature [LOW] in NZE and by the presence of the feature [LOW] in AE (with a three-way height distinction). The motivation for a non-low TRAP vowel in NZE stems from the fact that the NZE vowel change started with the TRAP vowel. Hence, it is also the most likely vowel to show lexical differences to its AE equivalent. Furthermore, we account for the production difference of the NZE TRAP vowel by exactly this non-low specification. It is more likely that a lexically non-low vowel is produced as mid vowel; otherwise, we would have to assume an additional rule which deletes [LOW] in the process of speech production.

As a consequence of these representation assumptions, a phonetically high vowel would be a nomismatch in NZE and a mismatch in AE. Further details of our feature-based hypotheses are given in the next section.

3 Assumed representations of NZE and AE vowels

We account for the vowel differences between NZE and AE in the following way, assuming partly different surface feature specifications in each dialect (see Table 2).

Table 2
Tongue height surface features of the short front vowels in NZE compared to AE

Lexical set	*NZE*	*AE*
TRAP	[–]	[LOW]
DRESS	[HIGH]	[–]
KIT	[HIGH]	[HIGH]

The crucial feature dimension is TONGUE HEIGHT, although ARTICULATOR place may co-vary. However, we simplify our assumptions by focusing on height features only.

As can be seen in Table 2, the TRAP vowel has a low realization in AE, but not in NZE.[4] Since the vowel change in NZE (in comparison to other English dialects) started with the TRAP vowel, we conjecture that its lexical feature representation is identical to the representations given in Table 2. Thus, it is an underlying low vowel in AE, but a non-low vowel in NZE. The lexical representations of the DRESS and KIT vowels may also be identical to the specifications given in Table 2, but they are not at stake here, since we are mainly interested in the surface features of these vowels. In this respect, the DRESS vowel is mid (i.e., [–]) in AE and high in NZE while the KIT vowel is high in both dialects.

The surface features are a direct repercussion of the extraction mechanism. For instance, [HIGH] is extracted from the DRESS vowel in a word uttered by an NZE speaker, while no height feature will be extracted if the same word were uttered by an AE speaker. We acknowledge that feature extraction as abstraction from fine-grained phonetic information may be tuned depending on speaker identity or social context (cf., Hay et al., 2006). On the other hand, lexical representations should be more stable, but may also change over time. For instance, we would model the change from a low TRAP vowel towards a mid TRAP vowel by the loss of the feature [LOW], even though other speakers in the community may still pronounce TRAP vowels as low vowels.

Our claim that the *representational* differences have direct consequences for lexical access of the noun stems in the two dialects is discussed in the next section in more detail.

4 Lexical access to the short front vowels

The lexical representations of the NZE short front vowels are accessed on the basis of the ternary matching algorithm described above. Lexical access is successful if there is no mismatch between signal and lexical representation, and vice versa, access is disrupted if there are conflicting features. Based on the tongue height dimension, the following possibilities arise (illustrated in Figure 2).

Given the assumptions regarding the perception of high, mid and low vowels, and the different representations of the short front vowels in the two dialects NZE and

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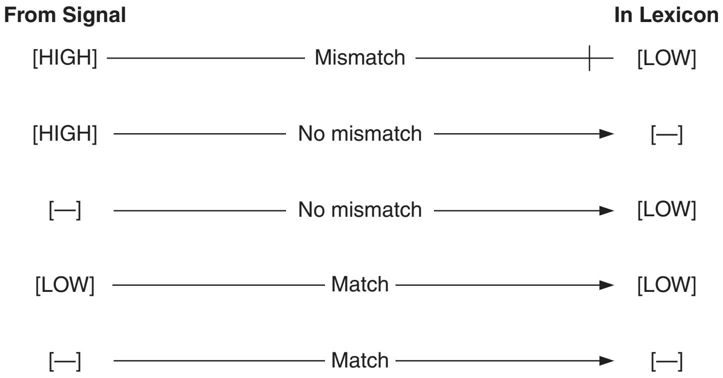
[4] Note that this implies the extraction of [LOW] from the signal in the FUL framework.

Figure 2

Mismatching, nomismatching and matching featural relations between the speech signal and the mental lexicon in the model according to Lahiri and Reetz (2002). Only contradictory features (i.e., high vs. low) lead to conflicts (mismatches) and do not activate the lexical representation. Mappings with unspecified segments in the signal or the lexicon are tolerated (no mismatches)



AE, we tested the lexical access of words containing the TRAP vowel in NZE and AE. We expect clear processing differences, based on the featural representation of the respective vowel in each variety and on the featural oppositions illustrated in Figure 2. Our precise predictions are formulated in the next section.

5 Experimental evidence for feature conflicts

5.1 Predictions based on representations

Minimally differing words such as *pen* and *pin* have different semantic relatives, in this case *ink* and *needle*, which clearly do not differ in a similarly minimal way. We distinguish "semantically related words" from "associatively related words." The former require a semantic relationship between each other, such as synonymy or hyponymy. Associative relatives, on the other hand, may just co-occur in specific phrases or be related by virtue of non-semantic relations. It has been shown that there is a processing difference between semantic and associative relations (cf., Perea & Rosa, 2002). We furthermore believe that semantic relations better reflect homogeneous relations between words, while associative relations can vary between speakers to a much higher degree.

Based on our assumptions regarding the different representations of the TRAP vowel in NZE and AE, we believe that the same acoustic tokens would differentially activate semantic relatives of words containing the TRAP vowel in the two dialects. In particular, we were interested in whether the phoneme sequence [pɪn] (with a phonetically high vowel) would activate *pot* (being a semantic relative of *pan*) in both NZE and AE or whether there would be differences on the basis of feature matches versus mismatches. We conjecture that the activation of *pot* by the phoneme sequence [pɪn] should be possible if this sequence is accepted as a variant of *pan*. In NZE, this should be the case, since the vowel in the sequence does not mismatch in the tongue height dimension with the lexical representation of the vowel in *pan*. In AE, however, the sequence [pɪn] is not an acceptable pronunciation variant of *pan* since, in our model, the high vowel mismatches with the representation of the TRAP vowel as [LOW].

We measured the lexical access to the words of interest (i.e., containing the TRAP vowel) in *priming* experiments. The extensive psycholinguistic literature suggests that priming is based on the successful pre-activation of a particular lexical representation (*target*) through an appropriate *prime* which is in some ways related to that representation (cf., Forster, 1999, and references therein). This relation can be semantic (e.g., *gnat–fly*; cf., Meyer & Schvaneveldt, 1971) or morphological (e.g., *added–add*; cf., Drews, 1996). The task in priming experiments is such that subjects see or hear a sequence of related and unrelated words and provide lexical decisions for the targets, that is, indicate whether the targets are actual words of the subjects' native language or not. It has been shown repeatedly that relations between primes and targets facilitate the lexical decision for the target, that is, subjects react faster. Priming is defined as the amount of target facilitation in the related condition compared to a control condition without prime–target relations. The measure of facilitation (priming) can then be used as an indicator of how the words are accessed and represented in the mental lexicon.

In this study, we used semantic priming and were interested in whether all members of a triplet such as *pin*, *pen*, and *pan*[5] would equally activate *pot*. We hypothesize that all three words can activate *pot* if their pronunciations were accepted as variants of *pan*, that is, if they do not conflict with the lexical representation of this word. Since all words minimally differ in their stem vowels, and the dimension of the differences is tongue height, we predict that based on the relations depicted in Figure 2, the phoneme sequence [pɪn] can activate *pan* due to a nomismatch with the lexical representation in NZE. Thereby, activation can spread to *pot*, that is, [pɪn] primes *pot*. In contrast, the same sequence cannot activate *pan* in AE, since the vowel is specified for [LOW], and therefore conflicts with [HIGH] from the signal. As a consequence, *pot* cannot be co-activated, and [pɪn] will not prime *pot* in AE. Note that with respect to the triplet *pin*, *pen* and *pan*, the phonetic sequence [pɪn] corresponds to different words in NZE and AE. In NZE, it is a (possible) realization of *pen* while in AE, it is a realization of *pin*. For our experiments, we used pronunciations of an NZE speaker with clearly high DRESS vowels. KIT vowels, on the other hand, are rather represented as mid vowels, although it is still likely that [HIGH] is extracted from the acoustic signal. If both DRESS and KIT vowels were high in NZE in their phonological representation, then they would have to contrast on another featural dimension (e.g., tongue root or place of articulation). In this article, however, we want to focus on the phonological representation of the TRAP vowel. Furthermore, our experiments do not bear on the phonological representation of the KIT vowel. Thus, while both *pin* and *pen* pronunciations should prime *pot* in NZE, only *pan* ought to prime *pot* in AE, since the other two conditions involve featural mismatches in the tongue height dimension. Note that the pronunciation of *pan* in NZE involves the mid vowel [ɛ]. Our priming assumptions are summarized in Table 3.

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[5] These items are exemplary for our stimuli set. We are aware that the final nasal has a different influence on the preceding vowel height than a stop or a liquid (cf., Thomas, 2004). In our stimuli set, we have different final consonants and not only sonorants.

Table 3
Priming predictions for a semantic priming experiment with different specifications of the TRAP vowel in NZE vs. AE. The stimuli stem from an NZE speaker

Prime vowel	KIT		DRESS		TRAP	
Example	pin		pen		pan	
	[pən]		[pɪn]		[pɛn]	
Surface features	[HIGH]		[HIGH]		[–]	
Lexical features	NZE	AE	NZE	AE	NZE	AE
(TRAP)	[–]	[LOW]	[–]	[LOW]	[–]	[LOW]
Match	nomismatch	mismatch	nomismatch	mismatch	match	nomismatch
Priming	✓	✗	✓	✗	✓	✓

Our predictions have been tested in a semantic priming experiment with NZE listeners (experiment 1) and AE listeners (experiment 2).

6 Experiment 1 (NZE stimuli, NZE listeners)

6.1 Material

Sixteen triplets of English minimal pairs with TRAP, DRESS and KIT stem vowels (exemplified by the stimuli *pan*, *pen* and *pin*) were selected as primes. Each of the 48 test primes was a monosyllabic noun with a short front vowel, conforming to the syllable structures CVC, CCVC, CVCC or CCVCC (mean length 3.3 segments, cf. Appendix).

The targets were selected as semantic relatives to the items with the TRAP vowel (e.g. *pot* for *pan*, mean length 3.2 segments). We tried to use semantically rather than associatively related word prime–target pairs for several reasons. First, as discussed before, semantic relations can better be generalized across speakers than can associative relations, possibly showing a high degree of inter-subject variation. Second, there is evidence that only a semantically related prime can actually tap into the meaning of the corresponding target (Perea & Rosa, 2002). Furthermore, Perea and Rosa (2002, p.188) showed that in the time course of the lexical decision task, purely semantic relations decay faster than associative or mixed relations. That is, by using only semantically related targets, potential priming effects *between* test-pairs or test-pairs and fillers are minimized.

The semantically related targets were chosen according to Webster's dictionary of synonyms (Gove, 1968) and cross-checked with WordNet (Miller, 2003). For the majority of the primes with the TRAP vowel, the semantic relative was a (near-)synonym. No semantic relative of these primes had a semantic relation to the other primes of the same triplet, i.e. the target for *pan* was *pot* and had no semantic relation to *pen* or *pin*. Additionally, semantically related and unrelated word pairs were tested in an offline judgment study. A close relation between the two words had to be rated by a small number (1 or 2) while the lack of a relation had to be indicated by a high number (4 or 5). The mean rating for the semantically related pairs was 2 and no pair was rated with a number higher than 3, while the mean rating for the unrelated pairs was 5, and no pair was rated with a number lower than 4.

Targets were also approximately matched to the frequency of their primes (48 per million [targets] vs. 49 per million [primes]), based on COBUILD Spoken Word Frequency, taken from CELEX (Baayen, Piepenbrock, & Gulikers, 1995).[6]

The experimental design involved three test conditions and one control condition. In the test conditions, the target with a semantic relation to the TRAP prime was preceded by the TRAP prime, by the DRESS prime, or by the KIT prime (e.g., *pan→pot*, *pen→pot*, *pin→pot*). In the control condition, the target was preceded by a noun without any semantic relation to that target, as established by the rating test reported above (e.g., *sense→pot*).

All four experimental conditions per target were distributed across four subject lists such that no subject heard a target twice. For instance, the first subject group was presented with the TRAP prime for its corresponding target, while the second group heard the DRESS prime, the third group the KIT prime, and the fourth group the control prime. Note that the experimental stimuli occurred always at the same places in each of the four subject lists. For instance, in group one, the fourth test pair was *pan→pot*, while it was *pen→pot* in group two, *pin→pot* in group three, and *sense→pot* in group four.

Since each of the crucial target nouns was always preceded either by one of the three test conditions or by the control condition in each subject group, there were 16 prime–target pairs per subject group. The Appendix provides the overall list of experimental stimuli and their distribution over the four subject groups.

Between the 16 prime–target pairs, filler pairs were inserted, varying randomly in number (3–4 between consecutive prime–target pairs). As for the prime–target pairs, subjects had to provide lexical decisions on the second member of each pair. The total number of filler pairs was 52, making up a total of 104 fillers, 68 of which were pseudo-words. Pseudo-words were derived from existing English monosyllabic nouns by changing one, two or three segments. All pseudo-words had a legal phonotactic structure and were cross-checked by a native NZE speaker for their validity. Pseudo-words only occurred as second presentations, that is, as the second member of each pair. There were 34 of such pairs for each group. Altogether, each subject group was assigned a total of 68 pairs (16 prime–target pairs, 52 filler pairs) and there were as many words as pseudo-words, guaranteeing unbiased lexical decisions.

The stimuli were read by a native speaker of NZE with phonetic training. The recording was done with a Sony Stereo microphone (ECMMS957). Stimuli were stored on a DAT-tape and subsequently digitized with the sound editing application Cool Edit Pro (Hain, 2003), using a sampling rate of 44.1 kHz (16 bit, mono).

6.2 Acoustic analysis of test stimuli

Prior to the acoustic analysis, the experimental stimuli were down-sampled to 11 kHz. Formant values (F1, F2, F3) were calculated using PRAAT (Boersma & Weenink, 2007). They stemmed from a Linear Predictive Coding (LPC) analysis[7] at the beginning, midpoint, and endpoint of each vowel and were averaged across these positions for further analyses (see Table 4).

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[6] A comparison of the COBUILD Spoken Word Frequency with both the Wellington Corpus of Spoken New Zealand English and the Canterbury Corpus revealed approximately the same frequency distribution for the test stimuli.

[7] The parameters were as follows: Step rate: 5 ms, window size: 25 ms, window type: Hanning, highest formant frequency: 5000 Hz.

Table 4
Formant values of the primes in experiments 1 and 2. The right-most column shows the formant values of the corresponding AE vowels (male speakers, taken from Peterson & Barney, 1952)

Vowel	*Formant*	*Frequency [Hz] (NZE)*	*Frequency [Hz] (AE)*
TRAP	F1	530	660
	F2	1884	1720
	F3	2622	2410
DRESS	F1	354	530
	F2	2055	1840
	F3	2617	2480
KIT	F1	465	390
	F2	1571	1990
	F3	2446	2550

For the purpose of this study, it was crucial to determine the differences in the perceived vowel height as indicated by the F1 values[8] across the three vowels. The F1 difference between all three vowels was significant, as shown by the main effect VOWEL in an Analysis of Variance (ANOVA) with the first formant frequency as independent variable, $F(2, 47) = 66.66$, $p < 0.001$. The same analysis was carried out for F2 and F3. The F2 values differed between all vowels, $F(2, 47) = 82.13$, $p < 0.001$. In contrast, F3, $F(2, 47) = 3.68$, $p < 0.03$, was the same for the TRAP and DRESS vowel, $t = 0.07$, $p < 0.9$, while it differed between the KIT and the TRAP vowel, $t = 2.39$, $p < 0.02$, and <e> and <i>, $t = 2.31$, $p < 0.02$. The latter observation indicates a difference in a dimension other than tongue, ensuring a perceptual differentiation of the respective vowels.

Euclidean distances within each of the 16 minimal sets representing the three NZE vowels (e.g., *pin–pen*, *pin–pan*, *pen–pan*) were calculated in the [F2-F1]/[F1][9] vowel space and differed significantly as shown by the ANOVA with the factor DISTANCE TYPE (TRAP–DRESS vowel, TRAP–KIT vowel, DRESS–KIT vowel; $F(2, 45) = 18.13$, $p < 0.001$).

Altogether, the acoustic analysis showed two important points. First, all three prime stem vowels had differing F1 and F2 values. Furthermore, the Euclidean distances differed between all vowels. Second, the F1 frequency of the DRESS vowel was always lower than that of the KIT vowel, supporting previous findings that in NZE, the DRESS vowel is more and more realized as a front, high vowel, while the KIT vowel is relatively lower and more centralized. From an acoustic point of view, it was thereby assured that the primes included a high front vowel (see Figure 3).[10]

6.3 Experimental setup

All experimental test pairs were pseudo-randomized and grouped into four subject lists. The time lag between prime and target (inter-stimulus interval, ISI) was 250 ms,

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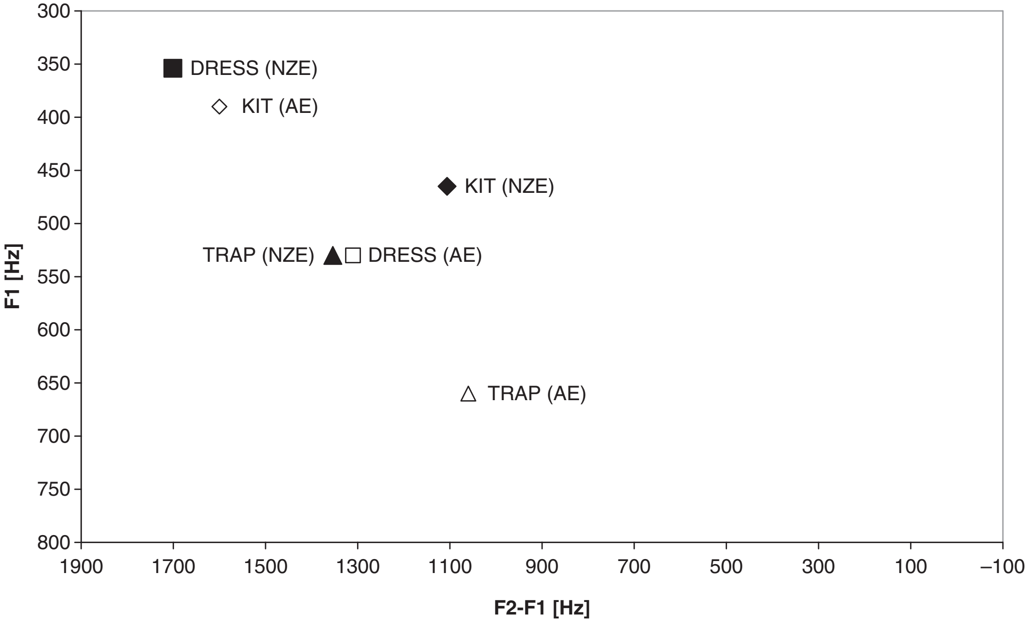
[8] Cf., Ladefoged (2001a, 2001b) and references therein; see also Pfitzinger (2003) and Kingston (1991).

[9] We use the F2/F2-F1 formant space according to its customariness as, for instance, shown by Ladefoged (2001a, 2001b).

Figure 3

Formant values (in Hz) of NZE and AE vowels in the [F2-F1]/F1 space (male speaker). The NZE formant measurements stem from the vowel edges and midpoints. The AE formants are taken from Peterson and Barney (1952)[10]



while the maximum response time (timeout) was 2000 ms. Reaction time measurement started at the onset of each stimulus. For each subject group, the experiment lasted for about 7 minutes, including an introduction and a training set of 10 pairs. Stimuli in the training set were similar (but not identical) to the stimuli in the main experiment.

6.4 Subjects and procedure

One hundred and ten students and affiliates of the University of Canterbury, Christchurch (all native speakers of New Zealand English, mean age 26, 50 males) took part in the experiment. They gave their informed consent and were paid for their participation.

Subjects received a written introduction and description of their task. They were told to listen to word pairs presented over stereo headphones (Sony MDR V300) and had to decide as quickly and accurately as possible whether the second word of each pair was an actual English word or not. Their reaction was recorded by pressing the appropriate buttons of a mobile reaction time measurement device (Reetz & Kleinmann, 2003). Subjects had to press the WORD button if they made a word decision and the PSEUDO-WORD button if they made a non-word decision. They had to use their index fingers to press the appropriate buttons. For a word decision,

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[10] As stated before, we use the F2/F2-F1 formant space according to its customariness as, for instance, shown by Ladefoged (2001a, 2001b). For similar reasons, we compare the NZE formant values to the Peterson and Barney data.

Table 5

Lexical decision times (Least Square Means in ms) of the four test conditions in experiment 1. The right-most column shows the percentage of incorrect target responses

Prime type	*Latency [ms]*	*Standard error*	*Incorrect responses*
CONTROL	949	8.7	2.3%
TRAP	914	9.4	1.1%
DRESS	925	8.5	2.2%
KIT	925	8.3	2.9%

right-handed subjects had to press the right button and left-handed subjects had to press the left button. Reaction times were recorded on a portable Power MAC.

The experiment was conducted in a quiet room in the Linguistics Department of the University of Canterbury (New Zealand).

6.5 Results

Wrong answers (i.e., word responses to a pseudo-word and vice versa) amounted to 5% in total. Timeouts did not exceed 0.6%. Among the targets, 3.1% wrong responses and 0.3% timeouts occurred. One target (*load*) and 2 subjects were excluded from further analyses. The excluded target had more than 50% wrong responses while the 2 subjects showed more than 15% wrong word responses.[11] Data points more than 2.5 standard deviations away from the mean were defined as outliers. These were excluded from further analyses.

A subsequent accuracy ANOVA with SUBJECT (as random variable, using the Restricted Maximum Likelihood Estimation[12]), TARGET and PRIME TYPE (CONTROL,[13] TRAP, DRESS and KIT) as independent factors did not show an effect of PRIME TYPE, $F(3, 1626) = 2.13$, $p < 0.1$. Thus, subjects were similarly accurate for all test pairs.

The Reaction Time (RT) ANOVA involved the factors SUBJECT, TARGET and PRIME TYPE (CONTROL, TRAP, DRESS, KIT, see Table 5). Crucially, the factor PRIME TYPE yielded reliable significance, $F(3, 1437) = 4.79$, $p < 0.003$, showing that the lexical decision times differed across conditions.

Priming was determined as facilitation of lexical decision in the test condition compared to the control condition. Hence, we were interested in significant lexical decision time differences between the control and the test conditions.

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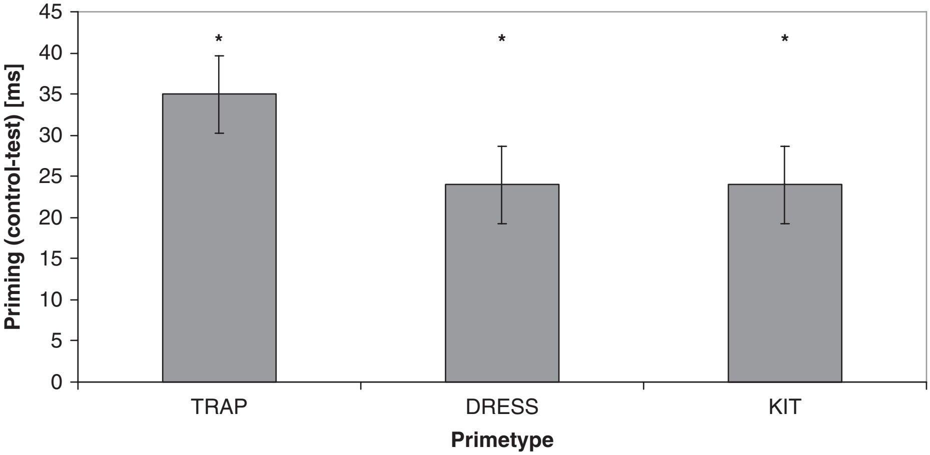
[11] We used these criteria based on their customariness in the literature (cf., Goldinger, 1996b, and references therein).

[12] The usage of a random effect for subjects is compatible with a "by subject analysis"; the restricted maximum likelihood (REML) estimation does not substitute missing values by estimated means and there is no need for synthetic denominators. For that reason, there was no separation of F-values into subject and item analysis.

[13] Note that CONTROL describes the condition where there is no relation between the two members of a trial pair.

Figure 4

Amount of priming per prime condition (prime type, experiment 1) as the target-based reaction time difference between the unrelated control and the corresponding test condition. Standard errors (+/–) are indicated on top of each bar (based on the reaction time differences). Reaction times are given as Least Square Means (LSM, in milliseconds). An asterisk marks significance, $p < 0.05$



Planned comparison within PRIME TYPE revealed significant priming for the TRAP primes (TRAP versus unrelated: $t = 3.62$, $p < 0.001$). In the other two conditions, DRESS and KIT primes yielded an equal amount of priming (DRESS versus unrelated: $t = 2.59$, $p < 0.01$; KIT versus unrelated: $t = 2.61$, $p < 0.01$).

In comparison to the TRAP primes, the priming in the DRESS and KIT conditions was not reduced. The priming differences between DRESS and TRAP primes and KIT and TRAP primes were not significant (DRESS–TRAP: $t = 1.04$, $p > 0.3$; KIT–TRAP: $t = -1.01$, $p > 0.31$). Also, the amount of priming between DRESS and KIT items did not differ (DRESS–KIT: $t = -0.02$, $p > 0.98$, see Figure 4).

In order to show that reaction times on targets were independent of prime- or target-properties, linear regressions were calculated.[14] First, it was checked whether the reaction times depended on the token frequency of the targets (COBUILD Spoken Word Frequency, CELEX). Although prime- and target-frequencies have been controlled for, there was a certain dispersion of frequencies across targets. The regression analysis of REACTION TIME (dependent variable) by TARGET FREQUENCY (independent variable) was significant, $F(1, 1561) = 13.50$, $p < 0.001$, but the correlation was rather weak, $R = 0.09$. A "by-condition" analysis revealed, however, that the correlation was significant in the control condition only (CONTROL: $F(1, 389) = 9.18$, $p < 0.004$; $R = 0.15$), but not in the test conditions (TRAP: $F(1, 389) = 2.92$, $p > 0.09$; DRESS: $F(1, 390) = 3.04$, $p > 0.09$; KIT: $F(1, 387) = 0.74$, $p > 0.39$). Another regression was calculated in order to determine

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[14] Correlations were calculated on the basis of the target data used for the reaction time ANOVA, that is, with excluded data.

whether the token frequency of the prime would influence the reaction time of the target. The linear regression of REACTION TIME (dependent variable) by PRIMEFREQUENCY (independent variable) showed no effect, $F(1, 1561) = 0.03$, $p > 0.87$, that is, there was no correlation between the frequency of the prime and the reaction time on the target.

Lastly, could the reaction times on the targets depend on the Euclidean distances between the TRAP vowel and the prime vowels of the DRESS and KIT condition? In other words, did it matter whether the acoustic distance between the prime vowel and the vowel of the word with the NZE TRAP vowel, through which the target was activated, was greater or smaller? We are aware that we are looking at just one simplified possibility of determining acoustic proximity, but the way we calculated the vowel distances is based on their acoustic main cues for tongue height and place of articulation, and should therefore provide a good first approximation.

In order to look for such a possible correlation between the distances of the KIT and DRESS vowels to the TRAP vowel and the reaction times in the corresponding experimental conditions, another linear regression was calculated with REACTION TIME as dependent variable and DISTANCE as independent variable (Euclidean distance of prime vowel to semantic relative of target, DRESS–TRAP and KIT–TRAP).

As expected from the reaction time ANOVA, the regression was not significant, $F(1, 812) = 0.19$, $p > 0.66$. A "by-condition" analysis also yielded no significance (DRESS primes: $F(1, 405) = 1.38$, $p > 0.24$; KIT primes: $F(1, 405) = 0.19$, $p > 0.66$). Hence, the reaction times were independent of the Euclidean distances between the prime vowels and the TRAP vowel.

6.6 Discussion

The semantic priming experiment with NZE short front vowels indicated that all members of the triplet *pan*, *pen* and *pin* can activate *pot* which is semantically related to the item containing the TRAP vowel, that is, *pan*. First, we found significant priming in the TRAP vowel condition, where we expected a full match between features extracted from the prime ([–] from the mid vowel /ɛ/) and the lexical representation of the TRAP vowel in NZE ([–] in the tongue height dimension). This effect simultaneously replicated previous findings of direct semantic priming experiments (Meyer & Schvaneveldt, 1971; Tabossi, 1996). Second, both DRESS and KIT primes significantly facilitated the lexical decision of their respective targets, that is, both *pen* and *pin* primed *pot*. We had expected this pattern of results, assuming that in NZE, pronunciations of *pen* and *pin* are accepted variants for *pan*. This is possible since the vowels in *pen* and *pin* do not mismatch with the lexical representation of the vowel in *pan*, through which the semantics of the target could be successfully pre-activated. Based on TONGUE HEIGHT and an NZE pronunciation, the vowel [ɪ] in *pen* was a nomismatch for the mid vowel /ɛ/ in *pan* since the feature [HIGH] from the signal was evaluated against [–] in the lexicon. A similar relation was given between the feature of the vowel in *pin* and the lexical representation of the TRAP vowel.

The full priming in the former two conditions supports the hypothesis that the TRAP vowel in NZE is underspecified for height in its lexical representation, so that the nomismatch between the height feature of the signal and the corresponding height feature in the mental lexicon was possible. There should not have been priming if [HIGH] were evaluated against [LOW].

By contrast, the acoustic distance between the prime vowels and the TRAP vowel significantly differed.[15] The DRESS vowel was further apart from the TRAP vowel compared to the distance of the KIT vowel and the TRAP vowel, and yet, the priming pattern did not reflect this acoustic difference. One could certainly imagine that priming is better if the prime vowel is acoustically closer[16] to the vowel in the semantic relative of the target. However, priming was similar for both DRESS and KIT primes and furthermore did not differ from the TRAP condition. Note, however, that there was a nominal priming difference between the TRAP and the other two conditions. While this points towards a graded activation of the respective semantically related target, the same gradual activation should have been observable between the DRESS and KIT primes. The lack of a graded effect between these conditions suggests that the priming pattern is best modeled by feature relations between the prime vowels and the TRAP vowels. The nominal difference between the amount of priming in the TRAP condition and the amount of priming in the other two conditions possibly reflected the difference between match (better priming) and nomismatch (slightly less priming), and not primarily the acoustic distances between the vowels in DRESS and TRAP and KIT and TRAP items.

The results of experiment 1 need complementation by AE subjects which have a three-way height contrast of their short front vowels. The crucial prediction is that a high vowel from the signal would be a mismatch for a low vowel in the lexicon. These tongue height feature oppositions occur if low representations of the TRAP vowel are accessed by primes with a phonetically high vowel. Regarding our experimental data, primes with both DRESS and KIT vowels fulfill these criteria. While the extraction of [HIGH] from DRESS vowels (uttered by an NZE speaker) is very likely, it is also possible that the same feature is (still) extracted from KIT vowels. The acoustic analysis and comparison with the Peterson and Barney data supports this assumption. In order to investigate priming effects in cases with featural mismatches, experiment 2 with the same stimuli as in experiment 1 was carried out. However, listeners were now native AE speakers. Note that a crucial difference to previous feature-based investigations is that the items bearing the conflicting features tended to be pseudo-words. For instance, in the Lahiri and Reetz (2002) study, primes minimally differed from existing words in the final segment (BAUN from BAUM ‘tree’) but did not exist as words. In experiment 2, by contrast, primes were existing English words. With the possible exception of KIT vowel stems, the nouns with TRAP and DRESS stem vowels are possible pronunciations of

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[15] Note that our acoustic measurements were a first approximation to multi-dimensional differences between the vowels in our stimuli. Since we base our feature extraction on primary acoustic cues, in this case, F1 and F2, we think that the relative distances in the vowel space based on these dimensions suffice to argue that it is the matching of extracted to stored features rather than the perception of acoustic differences which is at stake during lexical access. A more detailed acoustic model would have to take into account more dimensions as well as absolute positions (such as extrema) in the acoustic space. Furthermore, one would have to compare distances to prototypical positions in the vowel space, both within- and across dialects. This is certainly necessary future work.

[16] Note again that “acoustically closer” is a simplification here, since the notion throughout the discussion is based on Euclidean distances in the F2-F1/F1 space.

AE words, even though the meanings may differ. For instance, *pan* uttered by an NZE speaker equals the most likely pronunciation of *pen* in AE. The meaning differences, however, are irrelevant for the priming predictions. As long as the primes can activate the semantic relatives of the targets, priming ought to be observable.

7 Experiment 2 (NZE stimuli, AE listeners)

7.1 Rationale

Experiment 2 was set up in order to test the hypothesis that words with the low TRAP vowel in AE cannot be activated by primes with a high vowel. Hence, given the same stimuli as in experiment 1, there should be a lack of priming in the DRESS and KIT condition, while the TRAP condition should yield significant facilitation. In the latter condition, the features of the prime vowel and the lexical representation of the TRAP vowel do not conflict (see Table 3).

7.2 Material

Experiment 2 used the same material as experiment 1. Four stimuli lists, distributed over four subject groups, guaranteed that no participant heard a target more than once.

7.3 Subjects and procedure

Eighty-four students and affiliates of the University of Massachusetts in Amherst participated in the indirect semantic priming study. All subjects were native speakers of American English and originated from New England. They were paid for their participation or received class credits.

The procedure was exactly the same as in experiment 1 but involved different headphones (Sony MDR 7506 pro) and an iBook G4 for the recording of the reaction times. The experiment was conducted in a quiet room in the speech laboratory of the University of Massachusetts.

7.4 Results

Altogether, there were 18% wrong responses and 1.5% timeouts. Among the targets, wrong responses amounted to 14.2% while there were 1.5% timeouts. One subject had to be excluded since more than 15% of the word responses were wrong. Outliers were defined as in experiment 1.

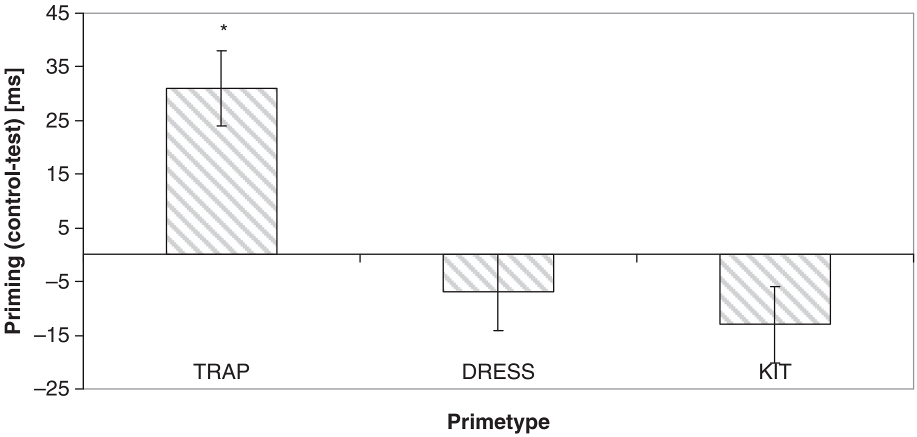
The accuracy ANOVA involved the factors SUBJECT, TARGET and PRIME TYPE (CONTROL, TRAP, DRESS and KIT). There was no PRIME TYPE effect, $F(3, 1222) = 1.22$, $p > 0.31$, although there were slightly more errors in the DRESS and KIT conditions (see Table 6). Note, however, that the absolute reaction times were slower and the errors higher than in experiment 1. This appears to be an artifact of the experiment. It could be based on pronunciations which deviated considerably from AE (most likely, in nouns with the KIT vowel).

The RT ANOVA comprising the factors SUBJECT, TARGET and PRIME TYPE (CONTROL, TRAP, DRESS and KIT), showed a significant PRIME TYPE effect, $F(3, 985) = 3.52$, $p < 0.02$. Planned comparisons revealed that priming was significant in the TRAP condition, $t = 2.08$, $p < 0.04$, but not in the two other conditions (DRESS primes; $t = -0.52$, $p > 0.60$, and KIT primes; $t = -0.95$, $p > 0.34$, see Figure 5).

Table 6
Lexical decision times (Least Square Means in ms) of the four test conditions in experiment 2. The right-most column shows the percentage of incorrect responses to the corresponding targets

Prime type	*Latency [ms]*	*Standard error*	*Incorrect responses*
CONTROL	1049	12.7	8.6%
TRAP	1018	12.2	8.9%
DRESS	1056	13.5	10.7%
KIT	1062	13.8	11.0%

Figure 5
Amount of priming per prime condition (prime type, experiment 2) as the target-based reaction time difference between the unrelated prime and the corresponding test prime condition. Standard errors (+/–) are indicated on top of each bar (based on differences). Reaction times are given as Least Square Means (LSM, in milliseconds). An asterisk marks significance, $p < 0.05$

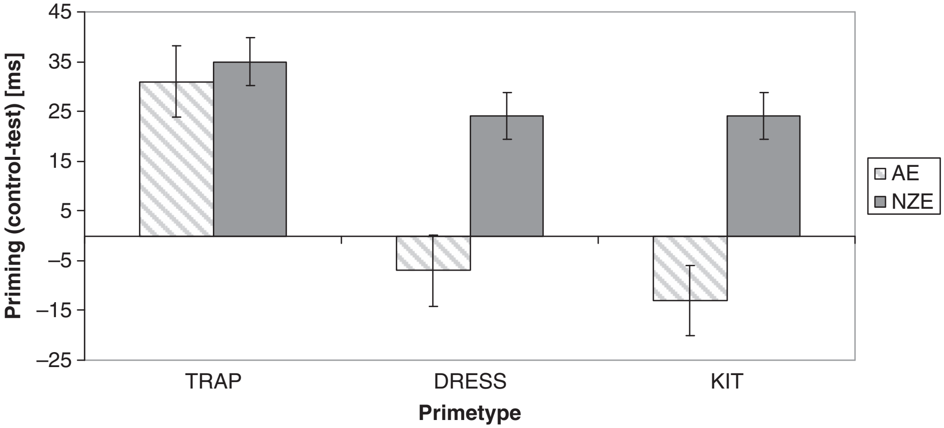


Furthermore, we tested whether the reaction times on the targets depended on their spoken frequency (COBUILD Spoken Frequency). The linear regression analysis was significant, $F(1, 1086) = 18.93$, $p < 0.001$, $R = 0.13$, but as before, a “by-condition” analysis showed that the significant correlation between target frequency and latency was restricted to the control condition, $F(1, 278) = 4.89$, $p < 0.03$, $R = 0.13$, to the DRESS condition, $F(1, 266) = 5.02$, $p < 0.03$, $R = 0.14$, and to the KIT condition, $F(1, 267) = 6.49$, $p < 0.02$, $R = 0.15$. Note that the latter two conditions showed no priming, i.e., the targets behaved as in the control condition. The regression was not significant in the TRAP condition, $F(1, 269) = 3.00$, $p < 0.09$. Another regression tested whether the reaction time on the target was dependent on the frequency of the corresponding prime. This analysis revealed that there was no significant correlation, $F(1, 1087) = 0.34$, $p > 0.56$.

Finally, could it be that the lexical decision times depended on the Euclidean distances between the prime vowels and a typical location of the AE TRAP vowel? In

Figure 6

Priming comparison between American English (AE: diagonal stripes) and New Zealand English (NZE: solid gray) listeners in experiments 1 and 2. The amount of priming corresponds to the differences between the control and the corresponding test conditions. Reaction times are given as Least Square Means (LSM, in milliseconds)



order to investigate this possibility, we calculated the differences between the formant values of the prime vowels and the formant values of the TRAP vowel as given by Peterson and Barney (1952). This correlation was not significant, $F(1, 535) = 0.61$, $p > 0.43$.

Experiments 1 and 2 were compared in a combined ANOVA with the factors SUBJECT, TARGET, PRIME TYPE, EXPERIMENT (NZE listeners, AE listeners, cf. Figure 6) and the interaction PRIME TYPE × EXPERIMENT. The factor PRIME TYPE was significant, $F(3, 2429) = 6.02$, $p < 0.001$. Crucially, PRIME TYPE interacted with EXPERIMENT, $F(3, 2429) = 2.46$, $p < 0.05$. Further analyses for each prime type showed that this interaction was not significant for the TRAP primes, $F(1, 1120) = 0.01$, $p < 0.91$, while it was significant for both DRESS, $F(1, 1118) = 3.7$, $p < 0.05$, and KIT primes, $F(1, 1115) = 4.9$, $p < 0.03$ (see Figure 6). This reflects that there were no differences in the direct semantic priming between NZE and AE listeners, whereas NZE and AE listeners clearly differed in the conditions where [HIGH] could be extracted from the primes.

7.5 Discussion

The most intriguing result of experiment 2 was that it replicated the semantic priming effect in the TRAP condition of experiment 1 (e.g., *pan*→*pot*) while there was no priming in the DRESS and KIT conditions (e.g., *pen*→*pot*, *pin*→*pot*). The DRESS and KIT primes (uttered by an NZE speaker) are thus not capable of activating TRAP words for AE listeners; otherwise, there should have been facilitation of their respective semantically related targets.

The lack of priming in the DRESS and KIT conditions was expected. In both conditions, the phonetically high vowel in the primes mismatched with the low TRAP vowel of the items, semantically related to the targets. For instance, the primes *pen* and *pin* could not activate *pan* and thereby failed to facilitate the recognition of its semantic relative *pot*. Note that we assumed that AE subjects still extracted [HIGH] from vowels in KIT words, pronounced by an NZE speaker. This is suggested by the location of this vowel in the F1/F2-F1 space (see Figure 3). Further evidence stems from a perception experiment in Scharinger (2006), which showed a differential identification of the short front vowels in an F1-continuum by NZE and AE listeners. Crucially, vowels which were classified as belonging to DRESS words by NZE listeners were classified as vowels of KIT words by AE listeners. Furthermore, the perceptual boundaries between the vowels in DRESS and KIT words in NZE and AE clearly differed. They were lower on the F1 scale for AE speakers than for NZE speakers. Thus, the vowel in NZE KIT words was closest to a high vowel for AE speakers.

An alternative interpretation of the results in experiment 2 could be that the realizations of the DRESS and KIT vowels were too deviant from the AE vowel exemplars. This interpretation is problematic, however, since the comparison of the acoustic measures between the NZE and AE vowels showed that NZE DRESS occupies the same acoustic space as AE KIT, while NZE KIT is closer to Schwa. It is possible that the KIT realizations of the NZE speaker were perceived as "foreign" vowels to a certain degree, which would also account for the slightly higher error rate in this condition. But even if this would be the case, it is unlikely that AE listeners would have perceived the DRESS vowel as similarly "foreign" as the KIT vowel. In the same vein, possible speaker effects (cf., Hay et al., 2006) are also an improbable explanation, since there were no problems with TRAP realizations. In fact, priming in the TRAP condition did not differ across NZE and AE listeners. If listeners adjusted to peculiarities of the speaker, why should they have done so selectively? Even if there was adjustment to the NZE dialect of the speaker, the assumptions regarding the feature extraction from the DRESS vowel would not differ.

8 General discussion

In our attempt to investigate lexical access of words which minimally differed in the dimension of tongue height, we compared two English dialects, NZE and AE. There is ample evidence that the NZE short front vowels, referred to by the lexical sets TRAP, DRESS and KIT, differ in their pronunciations from their AE counterparts (e.g., Gordon et al., 2004; Maclagan & Hay, 2004; Warren & Hay, 2006; Warren, Hay, & Thomas, 2008; Watson et al., 2000). The primary difference between the NZE and AE pronunciations relates to tongue height. Our assumption was that the pronunciation difference is also reflected in the lexical representation of the short front vowels, in particular with respect to the TRAP vowel, which is said to be the initial point of the NZE push chain (Gordon et al., 2004). In our speech perception model with a strong emphasis on phonological and categorical information in terms of discrete features (Lahiri & Reetz, 2002), the lexical differences between TRAP vowel representations in NZE and AE are realized by the absence versus the presence of the feature [LOW]. In particular, we assume that the TRAP vowel in NZE is not specified for tongue height, while it is low in AE. This featural difference should have access and processing consequences. We conjectured that in NZE, but not in AE, a word with a high front vowel (e.g., [pɪn]) can activate the minimal pair correspondent with the TRAP vowel (i.e., *pan*). In NZE, the feature [HIGH] does not conflict with the lexical representation of the TRAP vowel, which is mid. By contrast, [HIGH] *does* conflict with the lexical representation of the TRAP vowel in AE, since it is [LOW] in its lexical representation. By assumption,

[HIGH] and [LOW] are mutually exclusive, and thus mismatch. Note that words with a high front vowel can be provided by NZE pronunciations of *pen*, and to some degree by pronunciations of *pin* (cf., previous discussion).

We tested our predictions with two semantic priming experiments. The rationale was that if words with high vowels can activate words with the TRAP vowel, they should also activate semantically related words of the latter. For instance, the sequence [pɪn] should activate *pot* if it is accepted as a variant of *pan*, that is, if it does not conflict with the lexical representation of *pan*. The results of experiment 1 showed that in fact, words with high vowels primed semantic relatives of words with the TRAP vowel, suggesting that the TRAP vowel in these words has no tongue height specification [LOW]. We found that the priming effect was independent of stimulus frequencies. Furthermore, the reaction times did not depend on the Euclidean distances between the KIT/DRESS vowel and the TRAP vowel uttered by an NZE speaker in experiment 1. In experiment 2, there was no correlation of the Euclidean distances between the KIT/DRESS vowel and the TRAP vowel of averaged AE male speakers according to the data of Peterson and Barney (1952). Thus, it appears that priming was not modeled by the formant space distances between the prime vowels in the indirect semantic conditions and the TRAP vowel in NZE and AE.

Although it seemed that there were graded (but non-significant) effects in the priming of pairs like *pan→pot* as opposed to *pin→pot*, it was the featural relation between the prime vowels to the TRAP vowel which best accounted for the differences. A match relation led to more priming than a nomismatch relation.

The results of experiment 2 complemented the findings of experiment 1. Here, primes with high vowels did not cause a significant facilitation of their respective targets, semantically related to the minimal pair correspondent with the TRAP vowel. This suggests that the high vowel primes conflicted with the TRAP vowel words and thereby failed to facilitate their semantic relatives. We predicted this conflict on the basis of the mismatch between the prime vowel feature [HIGH] and the TRAP vowel feature [LOW] in AE with a three-way height contrast. Again, priming was not correlated with stimulus frequencies. We therefore conclude that categorical featural representations guide lexical access in speech perception.

Our emphasis on abstract phonological representations during speech perception may give rise to the impression that fine-grained phonetic information is rather neglected in our model. This is by no means our intention. Fine-grained phonetic information, which is much more integrated in exemplar models of speech perception and production (Bybee, 2001b; Goldinger, 1996a, 1998; Johnson, 1997; Pierrehumbert, 2001; Pisoni, 1997; Warren & Hay, 2006; Warren et al., 2008) is equally important for FUL in the process of feature extraction. It is beyond the scope of this article to provide a detailed account of the feature extraction mechanism, but we would like to mention that extra-linguistic variables (e.g., speaker identity, voice, social properties) can also affect the speed of processing in our model. Our assumptions are that the phonetic details are not part of the lexical representation of a word. Necessarily, we would have to assume that extra-linguistic variables can alter surface feature values and the way they are extracted. Note that FUL's emphasis on feature extraction and evaluation may be paralleled with abstraction mechanisms in exemplar models. We believe that abstraction is essential for the transformation of a continuous acoustic signal into discrete mental representations. Recent developments in exemplar theory seem to attribute more importance to this abstraction process (Goldinger, 2007).

Furthermore, we are aware of the fact that there is need for a more detailed acoustic analysis than we provided here by means of a Euclidean distance analysis. However, for such a study, clearly more than one speaker of each dialect is needed. We therefore did not extend our distance analysis to more than the F2-F1/F1 dimension and did not take into consideration absolute (extreme) positions in the respective vowel spaces, either.

From a theoretical perspective, our phonological emphasis may blur interface issues between phonetics and phonology (cf., Hawkins & Nguyen, 2003; Ohala, 1995; Scobbie, 2007), even more so since we assume a high degree of abstraction already at the stage of (phonetic) feature extraction. On the other hand, our assumption of early abstraction is supported by neurolinguistic findings. Early abstraction allows for early discrete units and categorical responses. In several studies, it has been shown that lexical and semantic effects during speech perception occur as early as 170 ms post stimulus onset (cf., Pulvermüller, Shtyrov, Illmoniemi, & Marslen-Wilson, 2006, and references therein). This, in turn, suggests that the incoming speech signal is very quickly translated into discrete representations, allowing for contrastive distinctions on the semantic level.

The issue of categorical versus gradient information also touches on the question of whether we would assume multiple lexical representations of the same words depending on speech style, social context or dialectal background. In particular, would someone from New Zealand build up a second representation of the TRAP vowel if he or she lived in America for a while? While we do not intend to account for individual lexical representations in every possible speaker for a social or dialectal community, we try to generalize across speakers of one such community. It may well be possible that individuals change their lexical representations of vowels and consonants. On the basis of underspecification, we would claim that individuals who are exposed to other dialects do not necessarily invoke two representations, but rather one, which may be more underspecified than a previous, native representation. For instance, an AE speaker maintaining a three-way height contrast for his or her short front vowels may alter the TRAP vowel representation from [LOW] to [–] if she or he lives in NZE. Vice versa, the New Zealander in America does not need to change his representation for the TRAP vowel (it is "underspecified" already). Rather, he would tune the feature extraction such that he would get [LOW] from the AE TRAP vowel and [–] from the DRESS vowel. Of course, these predictions have to be tested in future work, but provide a promising way of predicting asymmetries in language change.

In this respect, our model makes very explicit predictions for a putative study with an AE speaker who has a clear three-way height distinction of the short front vowels. In such a study with the same setup and stimuli as in experiments 1 and 2, there should be no priming for KIT–TRAP relations if listeners are AE speakers, but for the same stimuli, NZE speakers should show significant priming effects on the respective targets. This would be the result of a [HIGH] (signal)→[LOW] (lexicon) mismatch in the former and a [HIGH] (signal)→[–] (lexicon) nomismatch in the latter condition.

To conclude, the results of the two experiments with NZE and AE listeners provided evidence that lexical access is sensitive to categorical information during speech perception. We model this discrete information as contrastive phonological features which may conflict in certain dimensions. In this article, we focused on possible [HIGH]–[LOW] conflicts in the tongue height dimension and found evidence for categorical differences between the representations of the TRAP vowel in NZE and AE. We showed that there is a priming difference between NZE and AE, using the same stimuli, and we had predicted these differences on the basis of differences in featural relations between signal and lexical information. The advantage of this approach is that it provides a relatively simple account for the lexical activation of words through the abstracted properties from the speech signal.

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Appendix: Experimental stimuli (English nouns), ordered alphabetically by target

# In list	*Target*	*Prime group 1*	*Condition*	*Group 2*	*Condition*	*Group 3*	*Condition*	*Group 4*	*Condition*
49	boy	lad	TRAP	lead	DRESS	lid	KIT	flesh	CONTROL
71	bulk	shed	CONTROL	mass	TRAP	mess	DRESS	miss	KIT
64	chop	hick	KIT	fox	CONTROL	hack	TRAP	heck	DRESS
41	club	bet	DRESS	bit	KIT	camp	CONTROL	bat	TRAP
121	fly	gnat	TRAP	net	DRESS	knit	KIT	bridge	CONTROL
56	load	bass	CONTROL	pack	TRAP	peck	DRESS	pick	KIT
7	meat	hymn	KIT	van	CONTROL	ham	TRAP	hem	DRESS
24	plug	check	DRESS	chick	KIT	bill	CONTROL	jack	TRAP
32	pot	pan	TRAP	pen	DRESS	pin	KIT	sense	CONTROL
79	rail	milk	CONTROL	track	TRAP	trek	DRESS	trick	KIT
129	shelf	rick	KIT	health	CONTROL	rack	TRAP	wreck	DRESS
96	skill	neck	DRESS	nick	KIT	pub	CONTROL	knack	TRAP
17	talk	chat	TRAP	jet	DRESS	chit	KIT	blood	CONTROL
111	tap	wood	CONTROL	pat	TRAP	pet	DRESS	pit	KIT
103	tin	kin	KIT	wind	CONTROL	can	TRAP	ken	DRESS
86	trouble	fleck	DRESS	flick	KIT	list	CONTROL	flak	TRAP