*Constraints of Lexical Stress on Lexical Access in English: Evidence from Native and Non-native Listeners**

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Key words

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Abstract

Four cross-modal priming experiments and two forced-choice identification experiments investigated the use of suprasegmental cues to stress in the recognition of spoken English words, by native (English-speaking) and non-native (Dutch) listeners. Previous results had indicated that suprasegmental information was exploited in lexical access by Dutch but not by English listeners. For both listener groups, recognition of visually presented target words was faster, in comparison to a control condition, after stress-matching spoken primes, either monosyllabic (*mus-* from *MUsic / muSEum*) or bisyllabic (*admi-* from *ADmiral / admiRAtion*). For native listeners, the effect of stress-mismatching bisyllabic primes was not different from that of control primes, but mismatching monosyllabic primes produced partial facilitation. For non-native listeners, both bisyllabic and monosyllabic stress-mismatching primes produced partial facilitation. Native English listeners thus can exploit suprasegmental information in spoken-word recognition, but information from two syllables is used more effectively than information from one syllable. Dutch listeners are less proficient at using suprasegmental information in English than in their native language, but, as in their native language, use mono- and bisyllabic information to an equal extent. In forced-choice identification, Dutch listeners outperformed native listeners at correctly assigning a monosyllabic fragment (e.g., *mus-*) to one of two words differing in stress.

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1 Introduction

An English octopus is weaker in the middle than a Dutch octopus. The creature's name is spelled identically in the two languages, and in citation form is pronounced similarly in that in both languages stress falls on the initial syllable; however, in English the vowel in the middle syllable is the reduced vowel schwa, while in Dutch the vowel in the middle syllable is full.

This is one of the many manifestations of a systematic prosodic difference between English and Dutch. An unstressed syllable directly adjacent to a stressed syllable nearly always contains a reduced vowel in English, but quite often contains a full vowel in Dutch. There are many cognates of the *octopus* type; English *cigar* and Dutch *sigaar* [siɣar], English *cobra* and Dutch *cobra* [kobra], English *banana* and Dutch *banaan* [banan]—the list could be extended for several pages.

Formally, there are few other differences in the word prosody of the two languages. Both languages have stress rhythm; in both there is an opposition between strong syllables (with full vowels) and weak syllables (with reduced vowels); in both languages stress placement is not in a fixed position within the word but is in large part determined by syllable weight (Booij, 1995; Trommelen & Zonneveld, 1999). The most common pattern within the vocabulary of both languages is that stress tends to fall on initial syllables (Cutler & Carter, 1987; Schreuder & Baayen, 1994). The rules for stress placement listed by Trommelen and Zonneveld (1999) for the two languages are identical except for a single detail of what counts as a heavy syllable (in Dutch a heavy syllable is any closed syllable, in English it is a closed syllable or a syllable with a long vowel).

In any language with variable lexical stress, cues to stress are potentially available for use in spoken-word recognition. The process of recognizing words in speech involves simultaneous activation of multiple word candidates (Connine, Blasko, & Wang, 1994; Connine, Titone, Deelman, & Blasko, 1997; Marslen-Wilson, 1990; Zwitserlood, 1989) and subsequent competition between the concurrently active candidates (Goldinger, Luce, & Pisoni, 1989; McQueen, Norris, & Cutler, 1994). Incoming information is exploited to distinguish between the competitors as rapidly as possible (Marslen-Wilson & Warren, 1994; McQueen, Norris, & Cutler, 1999; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001). This incoming information potentially includes information about stress pattern. Thus in Dutch, the words *octopus* and *oktober* ('October') each begin with the same first four phonemes, but in *OCtopus* stress falls on the first syllable while in *okTOber* it falls on the second (henceforth, upper case signals stress placement). This means that the first syllable of *octopus* will be somewhat longer, may be somewhat louder, and will exhibit greater pitch movement than the first syllable of *oktober* (with the reverse being the case for the second syllables). If listeners can use these aspects of suprasegmental structure to distinguish one word from another, then they could tell the difference between *octopus* and *oktober* before the arrival of distinctive segmental information (the fifth phoneme).

Recent investigations of the use of stress in lexical activation and recognition have shown that listeners can indeed use such suprasegmental cues. Soto-Faraco et al. (2001) presented listeners, who were native speakers of Castilian Spanish, with spoken sentences (of a non-constraining type such as *He did not know how to write the word…*) ending with a word fragment which fully matched one of two potential words and differed from the other in just a single phoneme or in stress pattern. For instance, the fragment *prinCI-* (stressed on the second syllable) matches the first two syllables of the Spanish word *prinCIpio* 'beginning' and differs only in stress from the first two syllables of the Spanish word *PRINcipe* 'prince'. Likewise, the fragment *sardi-* matches *sardina* 'sardine' but mismatches *sardana* (a type of dance) in a single vowel, and the fragment *bofe-* fully matches *bofeton* 'smack' but mismatches *boletin* 'bulletin' in a single consonant.

At the offset of the word fragment listeners saw a string of letters on a screen and were asked to make a lexical decision about this visually presented string (see Zwitserlood, 1996, for a review of this kind of cross-modal priming task). Listeners' responses were significantly faster after fragments which matched the visually presented word (e.g., to SARDINA after *sardi-*, to PRINCIPIO after *prinCI-*, etc.) than after control fragments (e.g., *manti-*); responses after fragments which minimally mismatched and favored another word (e.g., to SARDINA after *sarda-*, to PRINCIPIO after *PRINci-*, etc.) were, crucially, significantly slower than responses after the same control fragments. This inhibition by mismatching information indicated, Soto-Faraco et al. argued, that the listeners had exploited the distinctive information rapidly to favor the matched competitor, which was thus enabled to compete more effectively and actually cause significant reduction in activation of its mismatched rival.

Soto-Faraco et al. found that suprasegmental cues to stress and segmental (vocalic or consonantal) information were used in exactly the same way: the pattern of results in the cross-modal fragment priming task was the same irrespective of the type of mismatching information which served to distinguish between two words.

Stress in Castilian Spanish does not involve an opposition between strong syllables with full vowels and weak syllables with reduced vowels; there is no vowel reduction in this language. The only correlates of stress are the suprasegmental features of relative duration, amplitude and pitch movement. In languages which allow vowel reduction, like English and Dutch, stress contrasts however often also involve segmental differences in that vowels in unstressed syllables tend to be reduced. Segmental information is arguably available earlier than suprasegmental information—it is known that cues within a vowel to the nature of the following consonant can, for instance, be effectively exploited in lexical recognition (Marslen-Wilson & Warren, 1994; McQueen et al., 1999; Whalen, 1991). Likewise, transitional information in a consonant can provide information about a following vowel (Strange, 1989). Where segmental information—whether or not correlated with stress differences—distinguishes words more rapidly than suprasegmental information, there may be little incentive for listeners to attend to the suprasegmental features.

In Dutch, nevertheless, listeners do make use of suprasegmental cues to stress in the word recognition process. For example, Cutler and Van Donselaar (2001) showed that stress information can remove competition from a word which it mismatches. Their experiment used the word-spotting task, in which listeners monitor short nonsense strings for the presence of an embedded real word. McQueen, Norris, and Cutler (1994) had shown that this task could reveal competition effects; the English word *mess* was detected more rapidly in the nonsense context *nemes* (which activates no strong competitor) than in *domes* (which activates *domestic*, competition from which slows the recognition of *mess*). Cutler and Van Donselaar replicated this result in Dutch: *zee* 'sea' was detected more rapidly in *luzee* (activating no dominant competitor) than in *muzee* (which activates the Dutch word *museum*; note that the fricative is not voiced in either *zee* or *museum*). However, when *muzee* was pronounced with stress on the first syllable *MUzee*, it no longer matched *muSEum* and there was no significant inhibition of the detection of *zee*.

In a subsequent experiment using the cross-modal fragment priming task, Cutler and Van Donselaar found that fragments like *muZEE* did indeed facilitate recognition of *MUSEUM* more effectively than stress-mismatching fragments (*MUzee*). But note that there is no Dutch word beginning *MUzee-*. Thus the experiment of Cutler and Van Donselaar could not show the competition-induced inhibition which Soto-Faraco et al. had produced by manipulating a minimal mismatch which could decide between two otherwise identical competitors. Van Donselaar, Koster, and Cutler (under revision) therefore replicated the Soto-Faraco et al. stress experiment in Dutch, presenting fragments like *octo-* which matched one of either *OCtopus* or *okTOber* and mismatched the other only in stress placement. They found the same result as Soto-Faraco et al. had observed: Compared with the case when the visual lexical decision was preceded by a control prime, responses preceded by a matching prime were significantly facilitated while responses preceded by a mismatching prime were slowed. Again, listeners were able to use the stress information to speed the victory of one of two competitors for lexical recognition.

Supporting evidence has also been provided by experiments in Dutch with other tasks, not involving on-line inter-word competition. In a study by Van Heuven (1988), truncated words were presented in sentence context and listeners were given a forced choice between two alternatives; their success rate at correctly assigning a syllable to one of two words in which it was respectively stressed versus unstressed (e.g., *si-* to *SIlo* vs. *siGAAR*) was high. In the same study, reconstruction of partially masked words in shadowing produced an even higher success rate. Experiments on the perception of mis-stressed words (using gating: van Heuven, 1985; van Leyden & van Heuven, 1996; or a semantic judgment task: Cutler & Koster, 2000; Koster & Cutler, 1997) have shown that mis-stressing harms word recognition in Dutch, and at least in Koster and Cutler's (1997) study the effects of mis-stressing were of similar magnitude to the effects of segmental mispronunciation.

As we observed above, Dutch and English are prosodically very similar. In marked contrast to the case with Dutch, however, it has proved very difficult to find any evidence that English listeners make use of suprasegmental cues to stress in word recognition. For instance, mis-stressing in English has little effect on word recognition: Small, Simon, and Goldberg (1988) found that mis-stressing did not inhibit word recognition if it effectively created the target word's stress pair (e.g., *INsert* pronounced as *inSERT* or vice versa), though recognition was significantly inhibited if the mis-stressing created a nonword (e.g., *chemist* pronounced *cheMIST*, or *polite* pronounced *POlite*). Similarly, Bond and Small (1983) found that word recognition in shadowing was achieved despite mis-stressing as long as the mis-stressing did not result in an alteration of vowel quality; Slowiaczek (1990) found the same for word identification in noise. Cutler and Clifton (1984) found that shifting stress without altering vowel quality had a much smaller adverse effect on recognition than stress shifts which changed full vowels to reduced or vice versa.

All these results suggest that segmental information outweighs suprasegmental information in lexical activation in English. Other evidence strengthens this conclusion. For instance, Slowiaczek (1991) presented listeners with a sentence context and a stress pattern (in the form of a noise-modulated transformation of a word's waveform, which preserved the word's amplitude envelope but obliterated formant and other spectral information), and asked them to judge a target word for acceptability; she found that the stress pattern information was often ignored, in that listeners responded yes to words which were semantically acceptable in the context but did not have the target stress pattern. A cross-splicing study by Fear, Cutler, and Butterfield (1995) confirmed that listeners pay more attention to the distinction between full and reduced vowels than to stress distinctions among full syllables. Listeners in this study heard tokens of words such as *audience*, *auditorium*, *audition*, *addition*, in which the initial vowels had been exchanged between words; they rated cross-splicings among any of the first three of these as insignificantly different from the original, unspliced tokens. Lower ratings were received only by cross-splicings involving an exchange between the initial vowel of *addition* (which is reduced) and the initial vowel of any of the other three words. Especially the vowels in stressed syllables seem to be important to listeners. Bond (1981) compared the disruptive effects on word recognition of several types of segmental distortion; most disruptive was distortion of vowels in stressed syllables. Likewise, Mattys and Samuel (1997) showed that mispronunciations in stressed syllables inhibited recognition of phantom words resulting from combination of dichotically presented input; a target word *generator* was likely to be erroneously detected where *generutor* in one ear was paired with *plimozakor* in the other, but not with *ginerator* and *plemozukor*.

The only priming study addressing stress effects in English involved not fragment priming but associate priming, and in minimal stress pairs: for example *FORbear* versus *forBEAR*, or *trusty* versus *trustee*. Such pairs are rare (in nearly all stress languages in fact) but a few do exist in English. Cutler (1986) found, using cross-modal associate priming, that presentation of either of the two members of such a pair activated words associated to both of them. Listeners heard sentences which were neutral prior to the occurrence of the critical pair, for example: *The person that she was hurrying to see was the trusty / trustee* ..., and made lexical decisions about words presented visually coincident with offset of the critical word, that is, the member of the minimal stress pair, in the sentence. Cutler found that whichever member of the stress pair had been heard, listeners' responses to associates of both members of the pair were facilitated in comparison to controls. Cutler argued that the undoubted suprasegmental differences between, for instance, *FORbear* and *forBEAR* were ineffective in constraining lexical activation, so that for English listeners *forbear* was effectively a homophone.

This aggregate body of evidence could mean that English listeners make very little or no use of suprasegmental stress cues in lexical access, while Dutch listeners do make use of such cues; in other words, despite the strong prosodic similarities between the two languages, their listeners process them differently. Alternatively, it could be that the Dutch evidence from priming techniques which tap activation and show competition, facilitation and inhibition effects is simply not paralleled by evidence from English because most of the experiments in English have used less sensitive tasks. For instance, Cutler's (1986) experiment with minimal stress pairs was of very limited power due to the fact that so few such pairs exist. An attempted replication of that experiment in

Dutch (Jongenburger, 1996) failed to produce any priming effects at all, despite the clear evidence from other studies of facilitatory effects of stress match in that language. Van Donselaar et al. (under revision) reported, besides their identity-priming experiments with fragment primes (e.g., *octo-* -OCTOPUS), a further study using fragment primes for associates of the truncated words (e.g., *para-* from *paradijs*, 'paradise' as a prime for HEMEL 'heaven'). The effects that they observed in associate priming were much weaker than the effects in identity priming, and they argued that while identity priming can provide a window on the initial stages of lexical activation and competition, associate priming effects may be limited to associates of word forms which have proven successful in the competition process.

A direct comparison of data for English with the findings of Soto-Faraco et al. for Spanish or of Van Donselaar et al. for Dutch cannot be made, since fragment priming experiments of the sort they conducted have not been undertaken in English. There is very good reason for this: Directly analogous experiments in English are impossible. This is because of the strong tendency in English for unstressed syllables adjacent to stressed syllables to contain reduced vowels. Thus there are effectively no such pairs in English as *octopus / oktober* in Dutch.

This does not however rule out partially comparable experiments. For instance, what is possible in English is to contrast pairs in which the stress placement contrast does not involve primary stress on the first syllable versus primary stress on the second syllable, but another placement contrast. In fact Soto-Faraco et al.'s stress experiment included some pairs contrasting primary stress on second versus third syllables (e.g., *coMEdia* 'comedy' vs. *comeDOR* 'dining room'), and so did Van Donselaar et al.'s Dutch fragment priming experiments (e.g., *paRAde* 'parade' vs. *paraDIJS* 'paradise'). These are again not possible to match exactly with English examples, since both the first and second syllables of the Spanish and Dutch pairs contain full vowels, and adjacent syllables with full vowels hardly occur in such words in English. However, a first- versus third-syllable contrast in primary stress can be achieved, if the requirement to use only syllables with full vowels is abandoned. There are in fact many English pairs in which the second syllable is reduced in both words, but primary stress on the first syllable in one member of the pair contrasts with primary stress on the third syllable in the other—for example, *admiral* versus *admiration*. In such pairs a fragment comprising only the first two syllables (e.g., *admi-*) would have primary stress plus a weak syllable in one case, and secondary stress plus a weak syllable in the other.

In the current study we use such pairs in a fragment priming study in English. We present native English-speaking listeners with non-constraining sentences ending with a truncated portion of a word (e.g., *admi-*) and measure their lexical decision responses to visually presented words (e.g., ADMIRAL) as a function of whether the stress pattern of the prime fragment matches the target word or its competitor.

We also present the same English materials to Dutch listeners. Dutch undergraduates are skilled users of English and, as many previous experiments from our laboratory have demonstrated, they are easily capable of carrying out laboratory listening experiments in that language. (It is unnecessary to carry out a pretest for English proficiency with this population, since such proficiency is a prerequisite for university entrance in the Netherlands.) By testing the two language groups with identical materials we can directly compare the relative use they make of stress information in lexical activation.

2 Experiments 1a and 1b

2.1 Method

2.1.1 Participants

Forty-eight native speakers of Australian English, members of the University of Melbourne community, took part in Experiment 1a. Because this experiment was conducted in the summer vacation, the participants—all teenagers or young adults—were nonacademic staff members, graduate students and relatives of staff members; only a minority of the participants had previously taken part in similar experiments. Fifty-six native speakers of Dutch, undergraduate members of the Nijmegen University community from the Max Planck Institute subject pool, took part in Experiment 1b. A further 24 Dutch speakers from the same population took part in the pretest. All participants had normal hearing and normal or corrected-to-normal vision; all received a small payment for their participation.

2.1.2 Materials

A search of the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993) produced 57 pairs of English words of the *admiral-admiration* type: one member with primary stress on the first syllable and an unstressed second syllable, the other with primary stress on the third (or in some cases fourth) syllable, secondary stress on the first syllable and an unstressed second syllable. Apart from the primary versus secondary stress difference on the first syllable, the first two syllables of the two words did not differ (i.e., segmentally they were the same; in this case, *admi-*). Each word had a frequency of occurrence of at least one per million.

A further selection among these pairs was then made via a pretest in which the 114 words were presented together with 26 other English words (some with high, some with low frequency of occurrence) to native speakers of Dutch. These participants read the words and, for each word, recorded whether or not they knew the word; if they did, they were asked (a) to give a Dutch translation, and (b) to rate how familiar they were with the English word, on a 7-point scale with 7 signaling high familiarity. From the results of this pretest 24 pairs were selected for use in the experiment; all chosen words were known by all participants and had received a mean familiarity rating of 4 or above. Twenty-three pairs were like *admiral-admiration*, that is, involved a first versus third syllable stress contrast; in one pair (*manicure-manifestation*) the contrast involved stress on the first versus fourth syllable. The 24 pairs are listed in the *Appendix*.

Ninety-six further control prime words and 10 filler prime words were chosen, matched to the experimental prime set in length and frequency. 154 short non-constraining sentences were constructed, of the type *They both approved of the*..., or *We were sure the word was*... These were used to make 10 practice prime strings (e.g., *Due to a printing error it said proposition*), 48 filler prime strings (e.g., *I think she'll like the explanation*) and 144 experimental prime strings. The latter formed 24 sets of six, in which for each of the 24 experimental pairs each of two sentences was completed with each member of the experimental prime pair and a control prime word. Thus for *admiral* and *admiration* the two sentences were *The speech therapist said*... and *Hank asked his wife to say*..., and each of these was constructed ending with *admiral*, ending with *admiration*, and ending with a control prime.

The materials were recorded onto Digital Audio Tape in a sound-attenuated cubicle by a male native speaker of Australian English. They were resampled to 16kHz and stored on computer. The final word of each sentence was truncated such that for the experimental pairs only the segmentally overlapping but suprasegmentally differentiated portion remained (e.g., *The speech therapist said admi-*). All control, practice and filler primes were also truncated in the same manner (e.g., *Hank asked his wife to say immer-*; *Due to a printing error it said propo-*; *I think she'll like the expla-*).

Eight presentation orders were constructed, each containing all filler items and 48 experimental sentences. Each of the 48 words was presented as visual target once in each presentation order, with (a) assignment to preceding sentence, (b) experimental versus control fragment prime, and, within experimental primes, (c) matching versus mismatching stress in the fragment, counterbalanced across presentation order. Thus, for instance, in presentation orders one to four ADMIRAL was preceded by a control fragment prime and ADMIRATION by an experimental prime, in two orders with matching and in two with mismatching stress, once of each with each potential sentence; in presentation orders five to eight ADMIRATION occurred in the control trials and ADMIRAL in the experimental trials.

2.1.3
Procedure

In Experiment 1a, the native listeners were tested individually in a sound-attenuated room. Six listeners heard each of the eight presentation orders. The materials were played from a DAT player over closed headphones; the lexical decision strings were presented in upper case, centered on the screen of a notebook computer. The listeners were given written instructions to listen to the auditory materials and to decide for each string appearing on the screen whether or not it was a real English word. Response keys labeled YES and NO were provided; YES responses were given with the dominant hand. Timing for each trial was initiated upon appearance of the visual string, and timing and response measurement were controlled by the computer via the NESU experimental control program.

In Experiment 1b, the non-native listeners were tested individually or in pairs in sound-attenuated booths. Seven listeners heard each presentation order. Written instructions were given in both English and Dutch. The materials were presented from disc by a personal computer running NESU. In all other respects the procedure was as in Experiment 1a.

2.2
Results and Discussion

Analyses of variance were conducted on the correct YES responses, separately across participants and across items. RTs below 100 ms were discarded. The error rate was quite high, at 11.4% for the native and 11.9% for the non-native participants, but an analysis of the missed responses, directly analogous to the RT analyses, produced no significant effects at all. Mean RTs for each group for the three priming conditions are shown in Figure 1.

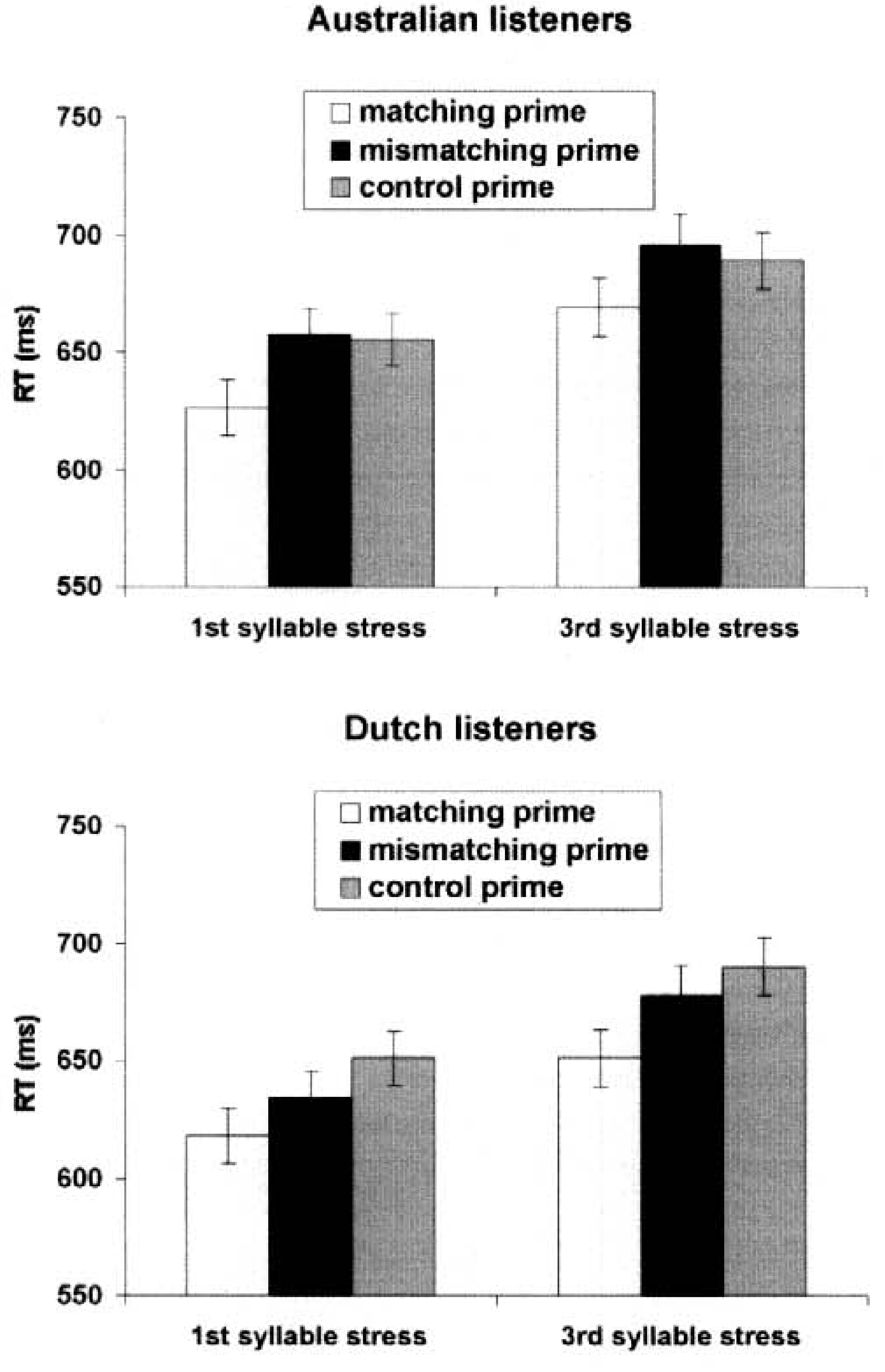

Figure 1

Mean lexical decision response times (RT) in ms, with standard error bars, to targets preceded by bisyllabic stress-matching, stress-mismatching and control primes in Experiment 1, separately for native (English-speaking: Experiment 1a) and non-native (Dutch-speaking: Experiment 1b) listeners

Combined analyses of both the native and non-native groups showed no RT differences between the two (but recall that a native group inexperienced in psychological experiments is here compared with a non-native group with considerable experimental practice). There was a significant difference between prime conditions, $F_1(2,204) = 22.82$, $p < .001$, $F_2(2,92) = 8.23$, $p < .001$, and a significant main effect of stress placement, words with primary stress on first syllable being recognized more rapidly than words with stress on the third syllable, $F_1(1,102)=45.92$, $p<.001$, $F_2(1,46)=13.32$, $p<.001$. Separate t-tests for each group revealed that for both native and non-native listeners, RTs were significantly faster to targets after fully matching primes (English 647 ms. Dutch 634 ms) than after either control primes, English 672 ms, $t_1(47)=3.54$, $p<.001$, $t_2(47)=2.22$, $p<.04$; Dutch 671 ms, $t_1(55)=4.79$, $p<.001$, $t_2(47)=4.49$, $p<.001$, or stress-mismatching primes, English 677 ms, $t_1(47)=4.41$, $p<.001$, $t_2(47)=2.39$, $p<.03$; Dutch 656 ms, $t_1(55)=3.01$, $p<.005$, $t_2(47)=2.35$, $p<.03$. RTs in the stress-mismatch condition did not differ significantly from those in the control condition for the native English-speaking group (both ts <1), but were significantly faster than the control for the non-native Dutch listeners, $t_1(55)=2.62$, $p<.02$, $t_2(47)=2.12$, $p<.04$.

The results of this study show that suprasegmental cues to the stress pattern of spoken English words can selectively constrain lexical activation for both native and non-native listeners. But note that the pattern of results differs from what was observed in otherwise analogous experiments in Spanish and Dutch; Soto-Faraco et al. (2001) and Van Donselaar et al. (under revision) found not only that target words were accepted significantly more rapidly after a stress-matching prime than after a control prime, but also that recognition after a stress-mismatching prime favoring a competitor word was significantly slower than after a control prime. This latter result has not been replicated in the present study with English.

The main effect of stress placement is presumably merely an artifact of word length and frequency, both of which play a strong role in visual lexical decision latency. Since the comparison of interest in the current study is between different primes for the same word, matching target words on these dimensions was not necessary—quite apart from the fact that it would in any case not have been possible with pairs such as we required. The words with initial stress were both shorter (mean length 8.333 letters) and higher in frequency (mean log frequency 2.31) than the words with stress on the third syllable (mean length 9.875 letters; mean log frequency 1.87).

A noteworthy result is also the parallelism of the pattern of results with the native and the non-native listeners. It might have been expected that the prime and target words would not be as easy for the Dutch listeners to process as for the native listeners; the words are overall relatively long and relatively low in frequency. Indeed, as noted above, the error rates were higher than, for example, in the study by Soto-Faraco et al. (2001), and this is plausibly due to the relatively lower frequency of the present target word set in comparison to the targets used in that earlier study. Nevertheless, it is clear that the non-native listeners were able to make very good use of the prime and to process the target words with great efficiency.

In our second set of experiments, we present listeners with still less of the prime word: a single syllable. Van Donselaar et al. (under revision) observed that Dutch listeners could effectively exploit stress information in monosyllabic fragments: responses were faster after stress-matching fragments than after control primes, just as was observed with bisyllabic fragments. With the monosyllabic fragments, however, Van Donselaar et al. observed no inhibition by stress-mismatching primes—these did not pattern differently from control primes.

The materials for the next experiment differ from those in the preceding one. The pairs used in Experiment 1 never involved a contrast between stress on the first versus second syllable, because English pairs of this type cannot, as explained, be found without accompanying segmental differences. The words with stress on the third syllable (e.g., *admiration*) all had secondary stress on the initial syllable. If, in our next experiment, we were to present only the first syllable of such pairs, listeners would be confronted with a contrast between primary versus secondary stress on the fragments, a distinction which is much harder to make than that between primary stressed and unstressed syllables (Lieberman, 1965). However, the use of monosyllabic fragments allows selection of words which differ from the second syllable onwards, and this in turn means that the unstressed fragments can be taken from words with stress on the second syllable — for example, *muSEum* contrasting with *MUsic*.

3 Experiments 2a and 2b

3.1 Method

3.1.1 Participants

Sixty-one native speakers of Australian English, undergraduate members of the University of Melbourne and University of New South Wales communities, took part in Experiment 2a; 56 native speakers of Dutch, from the same population as for Experiment 1b, took part in Experiment 2b. A further 12 native Dutch speakers from the same population took part in the pretest. All participants had normal hearing and normal or corrected-to-normal vision, and none had taken part in Experiment 1; all received a small payment for their participation.

3.1.2 Materials

A further search of the CELEX English database produced 30 potential pairs with segmentally identical first syllables but with respectively primary stress on the first syllable (e.g., *music*) or on the second but with no reduction in the first syllable (e.g., *museum*). These were pretested in the same manner as for Experiment 1, leading to selection of 21 pairs meeting the same criteria as used for Experiment 1. These 21 pairs are listed in the Appendix. Eight presentation orders were constructed, with all 42 target words occurring in each order, counterbalanced as in Experiment 1. The 42 preceding sentences had also been used in Experiment 1. Forty-two monosyllabic control fragments were used and 42 filler sentences, the latter again from Experiment 1.

3.1.3 Procedure

The procedure for Experiment 2a was as for Experiment 1a for listeners at the University of New South Wales, except that testing took place in a small quiet room; at the University of Melbourne listeners were tested in groups of up to seven in a quiet experimental room and the materials were presented from the hard disc of a computer running the Psyscope control program. In Experiment 2a six or seven listeners heard each presentation order. The procedure for Experiment 2b was as for Experiment 1b.

3.2
Results and Discussion

The results were analyzed in the same manner as for Experiment 1. Mean RTs for each group for the three priming conditions are shown in Figure 2. The miss rate was again high, at 16% for the native and 14% for the non-native listeners (but again this difference was nonsignificant, when analyzed in the same manner as the RTs).

In this experiment (in which comparable undergraduate populations were compared) there was a main effect of listener group on RTs: the Dutch responses, with mean of 660 ms, were slower than those of the native speakers: 601 ms, $F_1(1,115) = 15.78$, $p < .001$; $F_2(1,40) = 95.17$, $p < .001$. There was again a significant overall effect of prime condition, $F_1(2,230) = 67.74$, $p < .001$; $F_2(2,80) = 52.42$, $p < .001$, and of stress placement, $F_1(1,115) = 14.87$, $p < .001$; $F_2(1,40) = 6.23$, $p < .02$. Again the latter is presumably to be ascribed to length and frequency differences (initial stress words: mean length in letters 6.24, mean log frequency 2.18; second-syllable stress words: mean length in letters 6.76, mean log frequency 1.88).

T-tests comparing the prime conditions showed the same pattern for each listener group: RTs for targets preceded by fully matching primes (English 576ms.; Dutch 625 ms) were significantly faster than RTs for targets preceded by stress-mismatching primes, English 602 ms, $t_1(60) = 4.16$, $p < .001$; $t_2(41) = 2.88$, $p < .005$; Dutch 658 ms, $t_1(55) = 2.9$, $p < .005$; $t_2(41) = 3.73$, $p < .001$, and RTs to targets after stress-mismatching primes were significantly faster than RTs to targets after control primes, English 631 ms, $t_1(60) = 6.01$, $p < .001$; $t_2(41) = 4.57$, $p < .001$; Dutch 698 ms, $t_1(55) = 5.96$, $p < .001$; $t_2(41) = 4.46$, $p < .001$.

Together the experiments so far present an interesting pattern. English native speakers clearly show that they use the stress information in two syllables more effectively than the information in a single syllable: In Experiment 1a their RTs after stress-mismatching primes and after control primes did not differ, while in Experiment 2a the stress-mismatching primes produced facilitation in comparison to the control primes (albeit not as much as the stress-matching primes produced).

This asymmetry is reminiscent of the attenuation of the effects of stress observed by Van Donselaar et al. (under revision) in their experiments with Dutch native speakers listening to Dutch: there too the effects were stronger with two syllables of information. Overall, however, Van Donselaar et al. observed stronger effects with Dutch than the present native-listening experiments have produced for English: for Dutch, two syllables of information produced facilitation by stress match but inhibition by stress mismatch, while one syllable of information produced facilitation by stress match only. The latter pattern is in fact exactly the same pattern as our English native speakers showed with two syllables of information.

No such attenuation was observed, however, in the non-native Dutch listeners' performance across the present experiments. Their pattern of results in Experiment 1b and in Experiment 2b was effectively the same. The net effect is that they used the stress

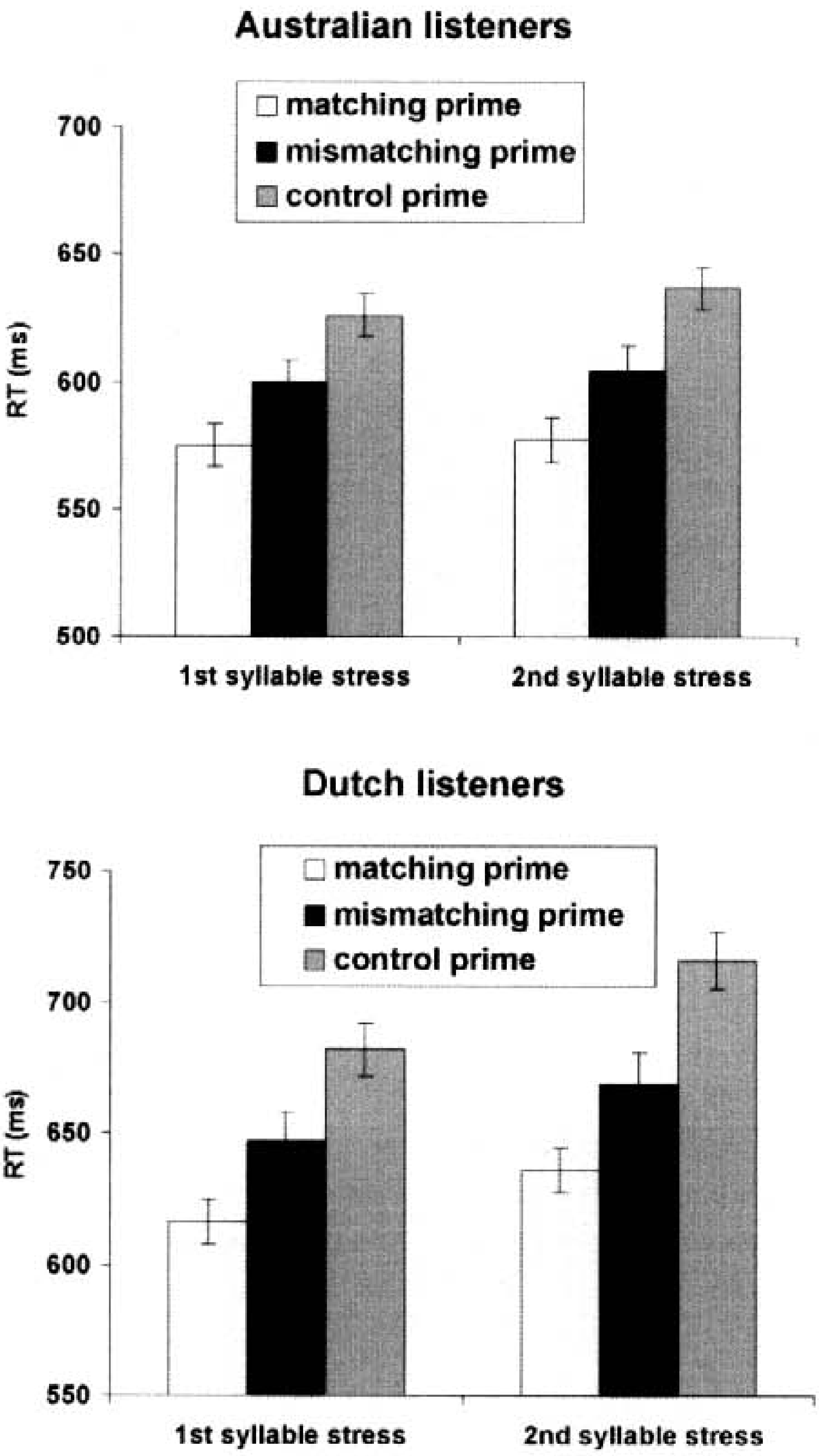

Figure 2

Mean lexical decision response times (RT) in ms, with standard error bars, to targets preceded by monosyllabic stress-matching, stress-mismatching and control primes in Experiment 2, separately for native (English-speaking: Experiment 2a) and non-native (Dutch-speaking: Experiment 2b) listeners

information a little less than the native listeners did in Experiment 1, but as effectively as the native listeners did in Experiment 2. This is impressive performance for non-native listeners, who might be expected to perform even less well than native listeners when less information is provided.

Besides Van Donselaar et al.'s (under revision) demonstration that Dutch listeners can make effective use of a single syllable's worth of stress information in their native language, Cutler and Van Donselaar (2001) also showed that Dutch listeners in an offline forced-choice identification task were extremely successful at judging the source of a single syllable given the choice between two words differing only in stress (e.g., *VOORnaam-voorNAAM*). In Experiment 3 we give our non-native listeners the opportunity to demonstrate this same facility with single syllables extracted from English words, again in comparison with native performance on the same task.

4 Experiments 3a and 3b

4.1
Method

4.1.1
Participants

Twenty-two native speakers of Australian English, undergraduate members of the University of New South Wales community, took part in Experiment 3a; 26 native speakers of Dutch, from the same population as for Experiments 1b and 2b, took part in Experiment 3b. All participants had normal hearing and normal or corrected-to-normal vision. None had participated in either of the two preceding experiments. They all received a small payment for their participation.

4.1.2
Materials

The materials were all the truncated words used in Experiments 2a and 2b, removed from their sentence contexts: 84 fragments in all (21 pairs $\times$ 2 source words $\times$ 2 sentence contexts). A tape was prepared with two occurrences of each fragment (168 tokens in all), in pseudo-random order (no successive occurrences of the same response pair), with 4.5 s of silence between tokens.

4.1.3
Procedure

Participants heard the tape over closed headphones in a quiet room. On each trial they circled on a response sheet the word of the response pair (e.g., MUSIC-MUSEUM) which they judged to be the source of the current fragment. For one presentation of each fragment the correct response was the left word of the pair, and for the other presentation the right word.

4.2
Results and Discussion

The results of both experiments are shown in Figure 3. As can be clearly seen, both listener groups achieved a higher degree of correct performance with the first-syllable-stress items (e.g., *music*). Great weight should not be attached to this result, given that it may reflect a bias to choose the higher-frequency response, or, alternatively, a bias to respond with a statistically more probable pattern (as we pointed out in the introduction, primary stress on the first syllable is the commonest pattern in the English vocabulary). There was no overall difference between the two listener groups in number of first-syllable-stress judgments (the English-speaking group made 62.5% first-syllable-stress judgments overall, the Dutch 57.5%, a nonsignificant difference).

What is more remarkable is that the overall percentage of correct assignments was higher for the non-native Dutch listeners (72.34% correct overall) than for the native English-speaking listeners (59.17% correct overall). This difference was indeed significant,

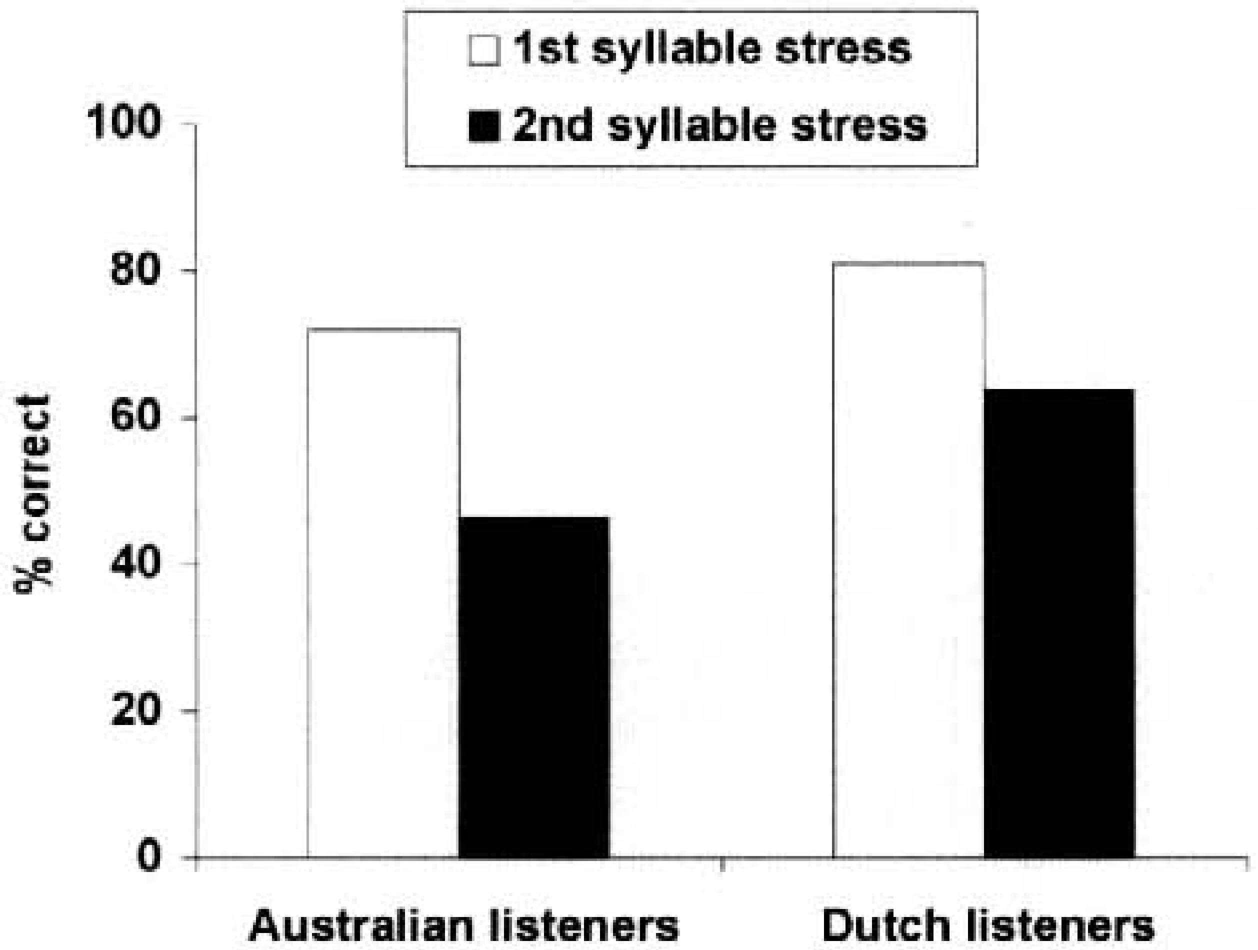

Figure 3

Mean percentage correct assignments of fragments from words with first- and second-syllable stress in Experiment 3, separately for native (English-speaking: Experiment 3a) and non-native (Dutch-speaking: Experiment 3b) listeners

$t_1(46) = 4.66$, $p < .001$. With fragments from initially-stressed words, the response bias makes interpretation of the scores difficult. However, the bias acted against the second-syllable-stress words, so analysis of the results for these items is particularly interesting; as Figure 3 shows, native listeners here actually scored below 50% correct. Binomial tests showed that the choice frequencies for each group differed significantly from chance with this subset of the items, but in different directions, the native listeners performing significantly worse than chance ($z = 3.19$, $p < .001$) and the non-native listeners significantly better than chance ($z = 12.9$, $p < .001$). Of the 22 native listeners, 10 listeners made more correct than incorrect judgments with these fragments and 12 listeners made more incorrect than correct judgments ($z < 1$). Of the 26 non-native Dutch listeners, 21 made more correct than incorrect judgments ($z = 2.94$, $p < .005$).

The results of this study certainly suggest that the task of making a forced choice identification of a syllable fragment as belonging to one of two potential source words may to a considerable extent be subject to response bias. However, response bias is not the only determinant of the result pattern: Listeners can also exploit suprasegmental information within the syllable in making their judgments. Remarkably, it appears that Dutch listeners are rather more skilled than native English listeners at exploiting this information in English fragments.

5 General Discussion

In six experiments we have examined the use of suprasegmental cues to stress in lexical activation and recognition in English, comparing the performance of native English-speaking listeners (for whom previous results had indicated that suprasegmental information was not easily exploited) with that of proficient listeners with Dutch as native language (for whom previous results had indicated that suprasegmental information was efficiently used in native listening). We have learned that the situation for the listening populations of the two languages differs less than previous results had led us to believe.

English listeners can make use of suprasegmental information in recognizing spoken words: *admi-* with initial primary stress activates ADMIRAL to a greater extent than ADMIRATION, while *admi-* with initial secondary stress activates ADMIRATION to a greater extent than ADMIRAL. Similarly, *mus-* with primary stress activates MUSIC more than MUSEUM, and *mus-* without primary stress activates MUSEUM more than MUSIC.

These results may be compared with findings from other languages in which studies with the same cross-modal fragment priming task have revealed that suprasegmental cues to stress pattern are exploited in the recognition of spoken words. In Spanish, a language with no vowel reduction, so that only suprasegmental information cues word stress, listeners can effectively use these suprasegmental cues to select among word candidates for recognition (Soto-Faraco et al., 2001). Experiments in Dutch, a language with vowel reduction and thus, as in English, with both segmental and suprasegmental correlates of stress, showed the same pattern (Van Donselaar et al., under revision). Other experiments on Dutch confirmed listeners' effective use of stress cues in lexical access (Cutler & Van Donselaar, 2001; Cutler & Koster, 2000; Jongenburger & Van Heuven, 1995; Koster & Cutler, 1997; Van Heuven, 1988), and similar cues can be used in the recognition of Indonesian (Van Zanten & Van Heuven, 1998).

The results are also comparable with evidence that listeners make use of other suprasegmental information which signals the prosodic structure of words. Thus in Japanese, listeners exploit pitch-accent information at an early stage of word recognition, as evidenced both by cross-modal fragment priming studies analogous to those performed here (Sekiguchi & Nakajima, 1999) and by gating studies in which only part of a syllable suffices to constrain listeners' word guesses to words with matching pitch accent patterns (Cutler & Otake, 1999).

Our first conclusion is thus that English does not appear to be the anomaly that previous failures to find effective exploitation of suprasegmental information (e.g., Cutler, 1986; Slowiaczek, 1991) might have led us to expect. Native English listeners can indeed exploit suprasegmental information in spoken-word recognition. However, the difference between Experiments 1a and 2a is evidence that information from two syllables is used more effectively than information from one syllable: only with bisyllabic fragments was there no residual facilitation in the stress-mismatch condition.

This is not to suggest that those earlier studies were inadequate; there is little doubt that replication would produce exactly the same result again. However, the power of an experiment like Cutler's (1986) study, using minimal stress pairs of the *trusty-trustee* type, is necessarily limited due to the very small number of such pairs in any stress language. Moreover, associate priming, as used by Cutler (1986), may offer less insight into the initial availability of multiple word candidates than identity priming, as used in Experiments 1 and 2 above. Van Donselaar et al. (under revision) found strong effects of stress pattern information in their identity priming experiments with Dutch, but in associate priming they found much weaker effects, which were arguably only of words which had already triumphed in the wordform competition process. Similarly, we have here shown with identity priming that, in English as in Dutch, stress information does constrain lexical activation.

Our second conclusion, however, in some sense modifies the first. The present results do differ in certain respects from the recent findings with other languages. In particular, the present study did not replicate the consistent finding from Spanish and Dutch fragment-priming Experiments (Soto-Faraco et al., 2001; Van Donselaar et al., under revision) that RTs to target words preceded by stress-mismatching primes were slower than RTs given control primes. Neither native nor non-native listeners of English produced this inhibition effect, with either monosyllabic or bisyllabic prime fragments.

Instead, for the non-native listeners with both types of prime, and for native listeners with monosyllabic primes, the stress mismatch condition produced partial facilitation. We consider that the most likely explanation of this pattern is that in English—as much previous work has indicated—there is a difference in the strength of segmental versus suprasegmental information. Segmental information weighs more strongly in lexical activation. This is exactly the conclusion that was reached by other authors who found, for instance, that mis-stressing English words has little effect on recognition unless a segmental alteration also results (Bond & Small, 1983; Cutler & Clifton, 1984; Small et al., 1988).

Even the performance of the native listeners in Experiment 1a, with bisyllabic fragments, is consistent with this claim. Although there was no residual priming in the stress-mismatch condition in this case, there was also no inhibition. This is again consistent with use of suprasegmental information which does not quite equal the speed and effectivity achieved by listeners in other languages.

Why should this be so? We suggest that English simply does not supply its listeners (whether native or proficient non-native) with as much opportunity for suprasegmental processing in word recognition as some other languages do. Recall that it was impossible to construct English fragment primes of the kind used in the earlier experiments with Spanish and Dutch—such as Dutch *OCto-* versus *okTO-* from *OCtopus* versus *okTOber*. In English the first two syllables of pairs like *octopus / October* differ segmentally as well as suprasegmentally. Words of more than two syllables commonly have full vowels in both the first and the second syllable in Dutch, and always do so in Spanish (which has no vowel reduction); but such sequences are extremely rare in English.

In addition, although both English and Dutch exhibit predominance of stress placement on word-initial syllables (Cutler & Carter, 1987; Schreuder & Baayen, 1994), the tendency is stronger in English, and in that language particularly marked in the words of Latinate origin. These form a good part of both vocabularies, but their stress pattern has been fitted to the native norm more thoroughly in English. In fact, such words furnished most of the pairs for the fragment priming studies in both languages, and it is notable that two-thirds of all the pairs in Van Donselaar et al.'s Dutch experiments involved words with non-initial stress which would have initial stress in their English cognates (often both members of the pair, e.g., Dutch *dyNAmo / dynaMIET*, English *DYnamo / DYnamite*; Dutch *kaBIne / kabiNET*, English *CAbin / CAbinet*; Dutch *koLOnie / koloNEL*, English *COlony / COlonel*).

These facts highlight how rarely English listeners will come across a segmentally ambiguous but suprasegmentally disambiguated fragment of speech. Such an experience will be more common for Spanish or Dutch listeners, who will thus be encouraged to exploit the suprasegmental information in the interests of listening efficiency. English listeners experience less such encouragement, and, as our results indicate, although they can use the suprasegmental cues they appear to use them less effectively than Spanish or Dutch listeners.

The performance of the non-native Dutch listeners with English in the two online experiments showed that they, too, did not use suprasegmental information in English as proficiently as they are able to in their native language. Their parallel performance in Experiments 1b and 2b did suggest that, as in their native language, they use mono- and bisyllabic information equally effectively. However, perhaps the most remarkable finding from the current study is that the performance of the Dutch listeners actually outstripped that of the native listeners in Experiment 3, the offline task in which subjects had full opportunity to process suprasegmental information without time pressure. Under these conditions, the Dutch listeners were able to apply abilities from their apparently superior native-language skills in suprasegmental processing to listening in their second language, English.

Previous research has of course shown repeatedly that native-language listening procedures are applied to foreign-language input. Work over the past several decades, for instance, has shown that segmentation of non-native speech input into its component words is often subjected to processing more appropriate to the native than to the non-native language; thus French listeners apply syllabic segmentation when they are listening to English (Cutler, Mehler, Norris & Segui, 1986) or to Japanese (Otake, Hatano, Cutler, & Mehler, 1993), although syllabic segmentation is appropriate for neither of these languages, as is clear from the fact that it is not applied by native listeners of either. Similarly, Japanese listeners apply moraic segmentation not only to their own language (Otake et al., 1993) but also to English (Cutler & Otake, 1994), French and Spanish (Otake, Hatano, & Yoneyama, 1996).

Language-specific cues to syllable boundaries are likewise applied inappropriately in non-native listening. English listeners find words like *lunch* easy to spot in nonsense sequences such as *moyshlunch* (because no native English words begin or end with a sequence *shl*, so that *shl* must have an internal boundary) but harder to spot in sequences such as *moyslunch* (because *sl* could be a word onset and thus has no necessary internal boundary). Yet proficient German listeners to English do not show this pattern — in fact their responses are somewhat slower to *lunch* in *moyshlunch* than *moyslunch* (Weber, 2001), presumably reflecting influence from German sequence constraints (in German, *shl* is a common word onset so has no internal boundary, whereas *sl* is not a possible syllable-initial or -final sequence, forcing an internal boundary of the same sort as for *shl* in English).

Native phonetic categories likewise override non-native categorical distinctions, making it difficult to discriminate phonetic contrasts which are necessary for correct perception of a non-native language, but which are irrelevant in the native language (Strange, 1995). This could in turn lead to word recognition false alarms, for instance of English *stem* as an embedded form within *stamp*, for Dutch listeners whose language contains no analog of this English vowel distinction (Broersma, 2002). Moreover, the native language vocabulary itself can be active during non-native listening; in eyetracking studies, listeners instructed to look at an object in their second language (e.g., *desk*) can erroneously look first at an object whose name in the native language only is confusable with the name of the target (e.g., lid, Dutch *deksel*; examples from Weber, 2001, see also Spivey & Marian, 1999).

These examples make it clear that carryover from the native language in second-language listening is usually not helpful at all, but rather harmful to efficient processing. Our current finding is thus remarkable because it produces a case in which native-language procedures applied in non-native English listening can actually produce better exploitation of available information than occurs in native English listening. We suspect that this situation may also occur with other types of speech information and other language pairs; for instance, non-native listeners may be more sensitive to allophonic distinctions in their second language if these map onto distinctions which are phonemic in their first language. However, we are not aware of experimental demonstrations of this type of performance, and our third and final conclusion from this study is thus that non-native listening can under certain circumstances achieve more effective exploitation of speech information than native listening.

The English *octopus* is weak in the middle. English listeners' use of what suprasegmental cues to word identity they encounter can also be termed weak. The Dutch *octopus* is stronger in the middle; and Dutch listeners are stronger at exploiting suprasegmental information in word recognition; even, given the opportunity, in English.

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Appendix

Word pairs used in the experiments. The first member of each pair has primary stress on the first syllable; the second member has primary stress on the third or fourth syllable (Experiment 1) or on the second syllable (Experiments 2 and 3).

Experiment 1:
admiral, admiration; analog, analytic; animal, anniversary; arrogant, aromatic; ceremony, cerebellum; compromise, comprehend; conference, confirmation; consequence, conservation; corridor, correspond; diagram, diabetes; enterprise, entertain; etiquette, etymology; exercise, exhibition; horrible, horizontal; immigrant, immature; impotent, impolite; interval, interfere; manicure, manifestation; metaphor, metamorphosis; motorbike, motivation; opera, opposition; prominent, promenade; property, propaganda; repertoire, repetition.

Experiments 2 and 3:
booking, bouquet; campus, campaign; carton, cartoon; cashew, cashier; convent, convex; distance, distinct; district, distress; diver, divert; harpist, harpoon; humid, humane; impact, impress; influence, inform; liquid, liqueur; massive, masseur; motive, motel; music, museum; mystic, mistake; robot, robust; ruler, roulette; typhus, typhoon; union, unique.