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Wilma van Donselaar^a, Mariëtte Koster^a, Anne Cutler^a

^a Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

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Exploring the role of lexical stress in lexical recognition

Wilma van Donselaar, Mariëtte Koster, and Anne Cutler

Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

Three cross-modal priming experiments examined the role of suprasegmental information in the processing of spoken words. All primes consisted of truncated spoken Dutch words. Recognition of visually presented word targets was facilitated by prior auditory presentation of the first two syllables of the same words as primes, but only if they were appropriately stressed (e.g., OKTOBER preceded by *okTO-*); inappropriate stress, compatible with another word (e.g., OKTOBER preceded by *OCto-*, the beginning of *octopus*), produced inhibition. Monosyllabic fragments (e.g., *OC-*) also produced facilitation when appropriately stressed; if inappropriately stressed, they produced neither facilitation nor inhibition. The bisyllabic fragments that were compatible with only one word produced facilitation to semantically associated words, but inappropriate stress caused no inhibition of associates. The results are explained within a model of spoken-word recognition involving competition between simultaneously activated phonological representations followed by activation of separate conceptual representations for strongly supported lexical candidates; at the level of the phonological representations, activation is modulated by both segmental and suprasegmental information.

Stress distinguishes a *hotdog* from a *hot dog*, a *trusty* from a *trustee*, a *desert* from a *dessert*. Lexical stress is one of the devices that languages use to distinguish one word form from another. In this study we examine how listeners use this source of information in identifying spoken words.

Stress is an abstract property of words, and its realization in the speech signal can take alternative forms. Many languages make no use of word stress at all, and in those languages that do exploit stress, it can not only be realized acoustically in different ways but can also be subject to differing rules governing where it may be placed within a polysyllabic word. For instance, in some languages word stress occurs at a fixed position, while in other languages

Correspondence should be addressed to Anne Cutler, MPI for Psycholinguistics, PO Box 310, 6500 AH Nijmegen, The Netherlands. Email: anne.cutler@mpi.nl

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stress placement is said to be free. Clearly, if the position of stress is fixed within all relevant words in a language, stress differences cannot be used to distinguish between words (though stress could then help to locate boundaries between words, which is another story altogether). If stress placement can vary, however, stress is available for a lexically distinctive function.

“Free” word stress does not mean that stress position is subject to no placement rules, but only that stress can occur at different positions in different words. In free-stress languages there is often a tendency for stress to fall more often in one position in the word than in others (thus in English, stress falls more often on word-initial syllables: Cutler & Carter, 1987). There are indeed rules for placement of stress in such languages, and they refer to factors such as syllable weight (number and type of phonemes in a syllable, and whether the syllable ends with a vowel or consonant, etc.). The acoustic realization of stress can involve a number of different dimensions: syllable duration, presence or degree of intonational movement, and acoustic salience expressed by pitch height or loudness; because these can vary to a certain extent independently of the nature of the phonemes in a syllable, they are referred to as “suprasegmental” factors. However, stress can also involve effects that are segmental (i.e., affect the nature of the phonemes): Vowel reduction in unstressed syllables is a segmental effect. Which dimensions are involved can interact with other aspects of a language’s phonology—for example, syllable duration may not be used if the language has vowel quantity distinctions (contrasts between long and short forms of the same vowels).

English and its etymological close relative Dutch both have free stress; both exhibit the tendency for stress to fall mainly on the initial syllable (Cutler & Carter, 1987; Schreuder & Baayen, 1994). Suprasegmentally, stressed syllables in these languages tend to be longer than unstressed syllables, and to be acoustically more salient and have greater intonational range. The stress placement rules (almost identical for the two languages: Trommelen & Zonneveld, 1999) are defined principally by syllable weight. Vowels can be reduced, and stressed syllables cannot contain reduced vowels (e.g., schwa, as in the first syllable of *dessert*).

The existence of segmental as well as suprasegmental correlates of stress variation is potentially important, because it affects the nature of the information to which listeners must attend if stress is to be used to constrain lexical activation on line. Whether a difference in stress translates partly to a segmental difference, or is purely realized in suprasegmental dimensions, can determine whether it is accurate to claim that listeners exploit stress in spoken-word recognition. Listener uptake of acoustic cues to segmental structure is efficient and rapid; coarticulatory cues to upcoming segments are exploited as soon as they are available (Martin & Bunnell, 1981, 1982; Marslen-Wilson & Warren, 1994; McQueen, Norris, & Cutler, 1999; Streeter & Nigro, 1979; Whalen, 1984, 1991). Moreover, information about vowel quality is available earlier than some suprasegmental phenomena such as pitch movement (Cutler & Chen, 1997). If reliable segmental cues adequately distinguish between words, there may be no need for listeners to attend to the later arriving suprasegmental information, and if the suprasegmental information is neglected, it is arguably improper to claim that stress information is being exploited, given that segmental information must be processed in any case. It is therefore important to examine the use of suprasegmental cues in languages in which segmental cues to the same distinction are available.

Listeners’ use of suprasegmental variation in lexical activation and recognition has been addressed in a number of different languages exhibiting different kinds of suprasegmental

structure—Chinese lexical tone (Yip, 2001; Yip, Leung, & Chen, 1998), pitch accent in Japanese (Cutler & Otake, 1999; Otake & Cutler, 1999; Sekiguchi & Nakajima, 1999). Suprasegmental cues to stress have been examined by Soto-Faraco, Sebastián-Gallés, and Cutler (2001), who directly compared the contribution of segmental versus suprasegmental mismatch information in lexical access via cross-modal identity priming by word fragments. In their experiments, which were conducted in Spanish, listeners heard nonconstraining sentences (such as *Nadie supo leer la palabra . . .*—“Nobody knew how to read the word . . .”), which ended with a truncated word. This truncated portion was fully compatible with one Spanish word but mismatched another in a single segment or in stress. For instance, the fragment *sardi-* matched *sardina* but mismatched *sardana*, and the fragment *prinCI*¹ matched *principio* but mismatched *principe*. At the offset of the word fragment a string of letters was presented on a computer screen, and the subjects’ task was to decide whether or not the string formed a real (Spanish) word. YES decisions to words were faster after matching fragments than after completely unrelated control fragments (thus PRINCIPPIO was recognized faster after *prinCI-* than after a control prime, and SARDINA was recognized faster after *sardi-* than after a control). However, YES decisions to words were not faster after minimally mismatching fragments; instead they were significantly slower than after the control (thus PRINCIPPIO was recognized significantly more slowly after *PRINci-* than after a control prime, and SARDINA was recognized significantly more slowly after *sarda-* than after a control).

Soto-Faraco et al. (2001) interpreted this result in terms of a competition model of lexical activation and recognition. Incoming speech input automatically activates word forms with which it is wholly or partially compatible, and simultaneously activated word candidates compete with one another for shared portions of the input. Mismatching information is used immediately to favour words it matches, as a consequence of which they can compete effectively with, and indeed inhibit, mismatched words.

Across four experiments Soto-Faraco et al. (2001) observed a consistent pattern of results: The facilitation for matching primes and inhibition from mismatching primes patterned similarly whether the mismatch involved a single-feature consonantal difference, a multifeature consonantal difference, a vowel difference, or a stress difference. Thus stress is used in Spanish in the same manner as segmental information to constrain lexical access.

The fragment priming experiments of Soto-Faraco et al. (2001) on stress cannot be exactly replicated in English: English has no pairs of words of more than two syllables in which the first two syllables contain full vowels and exhibit the suprasegmental contrast of *PRINcipe* versus *prinCIpio*. The nearest one can get is a contrast between pairs with an unstressed second syllable, in which the first syllable has primary stress in one of the words and secondary stress in the other. Such a pair is *ADmiral*–*admiRAtion*, for example. Cooper, Cutler, and Wales (2002) conducted a fragment-priming experiment, analogous to Soto-Faraco et al.’s stress study, with such pairs, and, interestingly, their results with English listeners differed from what Soto-Faraco et al. had observed with Spanish listeners. Cooper et al. found that YES decisions to words were indeed faster after stress-matching fragments

¹ Upper case on part of a word will be used to signify primary stress location. Words entirely in upper case are the visual target words in the priming experiments.

than after control fragments (thus ADMIRAL was recognized faster after *ADmi-* than after a control prime); but decisions were not significantly slowed by stress mismatch (thus ADMIRAL was recognized as quickly after *admi-* from *admiRAtion* as after the control).

The failure of stress mismatch to cause inhibition suggests that the suprasegmental information was not exploited as rapidly or as effectively in Cooper et al.'s (2002) study as in Soto-Faraco's (2001) experiment; *admiration* did not increase its activation due to the stress pattern of *admi-* enough, or quickly enough, to cause measurable inhibition of *admiral*. But the precise reason for this lessened efficiency in the English experiment is unclear. On the one hand, the source could lie in the materials: By this account, a contrast between a primary stressed syllable plus unstressed syllable and a secondary stressed syllable plus unstressed syllable could be insufficient to allow effective use of suprasegmental information in lexical activation. On the other hand, the source could be located in the listeners themselves: By this account, English listeners could be less efficient at using suprasegmental cues to word identity because their language provides abundant segmental correlates of stress contrasts.

Cooper et al.'s (2002) finding contrasts not only with the data from Spanish, but also with previous data from English. Here the contrast lies, however, in Cooper et al.'s evidence that English listeners can indeed use suprasegmental cues to stress in lexical activation, because many prior studies have indicated that this is not so. Thus mis-stressing has been reported to cause no significant delay of word recognition in English as long as segments remain unchanged (Bond & Small, 1983; Slowiczek, 1990, 1991; Small, Simon, & Goldberg, 1988). In a cross-modal associative-priming study, Cutler (1986) found that minimal English stress pairs such as *FORbear-forBEAR* primed each other's associates, suggesting that listeners treated them as effectively homophonous in defiance of the suprasegmental distinction.

These latter findings suggest that it may be justified to view the lack of inhibitory effects in Cooper et al.'s (2002) results as arising from reduced listener reliance on suprasegmental information, rather than from reduced stress information in the chosen materials. On the other hand, other recent findings cast doubt on the comparability of at least the earlier associative-priming result with the more recent fragment-priming data; associative priming can be absent even with materials that provide robust identity priming (Norris, Cutler, McQueen, & Butterfield, 2003). Because the materials used by Cooper et al. were the only kind that it is possible to use in this kind of experiment in English, the issue cannot be tested directly in that language. However, a direct test is possible in a phonologically very similar language, namely Dutch. Stress in Dutch, as in English, has widespread segmental reflections. But unlike English, Dutch has word pairs displaying a stress contrast in two successive syllables with full vowels, so that fragment-priming materials directly analogous to those used in Soto-Faraco et al.'s Spanish study can be constructed.

Previous experiments in Dutch have confirmed that listeners can use stress to resolve inter-word competition. A word-spotting study (in which listeners monitor short non-sense strings for the presence of an embedded real word) by Cutler and Donselaar (2001) showed that Dutch *zee*, "sea", was detected more rapidly in *luzee* (activating no serious competitor) than in *muzeer* (which activates the Dutch word *museum*). However, when *muzeer* was pronounced with stress on the first syllable, *MUzeer*, it no longer matched *muSEum* and there was no significant inhibition of the detection of *zee*. In a follow-up experiment using cross-modal fragment priming, Cutler and Donselaar further found that fragments like *muZEE* indeed facilitated recognition of MUSEUM more effectively than

did stress-mismatching fragments (*MUzee*). Note that the mismatching fragments in this latter study did not activate potential competitor words, since neither of them forms a potential word beginning in Dutch. Thus Cutler and Donselaar's experiment could not test for the competition-induced inhibition that Soto-Faraco et al. (2001) had produced by manipulating a minimal mismatch distinguishing between two competitors with otherwise identical initial portions.

Experiment 1, below, is a more direct Dutch analogue of Soto-Faraco et al.'s (2001) stress study. Via cross-modal fragment priming, the relative facilitatory effects of stress-matching and stress-mismatching bisyllabic fragments versus control fragments are compared. Thus the response time (RT) to decide that OKTOBER ('October') is a word is compared given the matching prime fragment *okTO-*, the mismatching fragment *OCto-* (a match to *OCtopus*, 'octopus'), or the control fragment *eufo-* (from *euforie*, 'euphoria'). If Dutch listeners exploit suprasegmental information efficiently to resolve competition, then, like Soto-Faraco et al., we should find that RTs after a stress-mismatching prime are significantly slower than after a control prime. That is, OKTOBER should be recognized fastest after *okTO-*, less rapidly after *eufo-*, and less rapidly again after *OCto-*. If suprasegmental information about stress is simply less important in Dutch than in Spanish (because Dutch has segmental correlates of stress distinctions while Spanish does not), then, like Cooper et al. (2002), we should find no such inhibition. Indeed we might possibly observe some residual facilitation, as Cutler and Donselaar (2001) did for the case of stress mismatches that do not resolve a competition between two potential words. In that case OKTOBER should be recognized fastest after *okTO-*, less rapidly after *OCto-*, and less rapidly again after *eufo-*. Finally, by comparing stress contrasts of different kinds (e.g., *okTOber-OCtopus* vs. *paRAde-paraDIJS*, 'parade-paradise') we can assess whether contrasts indeed differ in how effectively listeners can use them.

EXPERIMENT 1

Method

Participants

A total of 142 native speakers of Dutch, undergraduates at the University of Nijmegen and members of the Max Planck Institute for Psycholinguistics subject pool, took part in the experiment, 80 in the pretest and 62 others in the main experiment. All had normal hearing and normal or corrected-to-normal vision. They were paid a small sum for participating.

Materials

Thirty-five pairs of Dutch words were selected from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). Within each pair the two initial syllables of the words shared segmental structure, but differed in stress pattern. An example is *OCtopus-okTOber*. Note that (unlike in English) there is no difference in Dutch between the vowels in the second syllables of these words—both contain the full vowel [o] with no vowel reduction. Some pairs, such as this, involved a contrast between primary stress on the first versus second syllable. Others involved a second versus third syllable contrast in primary stress (e.g., *paRAde-paraDIJS*), or a first versus third syllable contrast (e.g., *DOminee-domiNANT*, 'pastor-dominant'). Primary stress on the third syllable was always accompanied by secondary stress on the first syllable.

Seventy sentences of the type used by Soto-Faraco et al. (2001) were constructed. Examples are *Door een zetfout stond er . . .* (“Because of a printing error it said . . .”), and *Het nieuwe schip droeg de naam . . .* (“The new ship was named . . .”). Such carrier sentences, semantically nonconstraining and varying in length and rhythm, provide a natural acoustic context for a word fragment without allowing listeners to predict the point at which the target would occur. All materials were recorded on Digital Audio Tape at 16 kHz by a female native speaker of Dutch. Each experimental word pair was assigned two of the sentences, and each member of the pair was recorded with each of these sentences, giving four recorded sentences per word pair. For instance, each of *octopus* and *oktober* occurred with each of the two example sentences given here. The experimental words formed the final words of the sentences. Each sentence was also recorded with a third control word. Forty similar filler sentences were also recorded.

The recordings were edited such that the experimental words were truncated at the end of their second syllable. Thus both *OCto-* (from *octopus*) and *okTO-* (from *oktober*) occurred at the end of each of two sentences.

A pretest was carried out in which the 140 potential experimental sentences (35 pairs \times 2 members \times 2 sentences) were presented to listeners who were asked to write down the full forms of the truncated words. The 140 sentences were divided into four sets such that each set contained only one of the 4 sentences recorded for each pair. A total of 20 listeners heard each set of 35 sentences ending in truncated words over headphones and wrote their word guesses on a response sheet.

On the basis of this pretest, 20 pairs were selected for the experiment proper. All selected experimental words had received correctly stressed responses from at least 57.5% of participants in the pretest (average across the set 85%), and no members of a single pair differed by more than 20% in correct responses. A total of 6 pairs involved a primary stress contrast between first and second syllable, 3 between first and third, and 11 between second and third. In most cases the third syllable of the two words began with the same segment or with another segment with the same place of articulation (e.g., as in *octopus-oktober*). The selected word pairs are listed in the Appendix. (Note that even where spelling differs, as in *fysicus-visite*, “physicist-visit”, the first two syllables were pronounced the same.) Duration, mean fundamental frequency (F0), F0 range (maximum F0 values minus minimum F0 values), and mean amplitude were determined for each of the first two syllables of each chosen word; Table 1 summarizes these data, separately for each of the three types of contrast.

Four sets of materials, each containing 80 experimental trials and 96 filler trials, were constructed for use in the cross-modal priming experiment proper. Each set was divided into two halves. Both members of each of the 20 selected word pairs occurred once as lexical decision target word in each half set. In each half, one word was preceded by an experimental prime (e.g., OCTOPUS by *Door een zetfout stond er okTO-*) and the other by a control prime (e.g., OKTOBER by *Het nieuwe schip droeg de naam eufo-*). In the second half the experimentally primed target from the first half was preceded by a control prime (e.g., OCTOPUS preceded by *eufo-*), and the control-primed target from the first half was preceded by an experimental prime (which was a matching prime for pairs where a mismatching prime had occurred in the first half, e.g., *okTO-OKTOBER* for the example above, and a mismatching prime for pairs where a matching prime had occurred in the first half, e.g., *OCto-OKTOBER* where *OCto-OCTOPUS* had occurred in the first half).

Across the four sets, each of the four possible prime-target pairings for each word pair (e.g., *OCto-OCTOPUS*; *okTO-OCTOPUS*; *OCto-OKTOBER*; *okTO-OKTOBER*) occurred once in a first half and once in a second half. Thus the first halves of the four sets constituted a complete experiment, and so did the second halves. Besides the experimental and control items, each half contained eight warmup filler items with real-word targets and 40 filler items with nonword targets. A total of 16 of the 48 filler primes in each half ended with a truncated word, which began similarly to the word or nonword target. The experiment began with a 16-item practice session of similar make-up to the experiment as a whole.

TABLE 1
Mean values for duration, mean F0, F0 range, and amplitude for first and second syllables of the stimuli used in Experiments 1 and 2, and Experiment 3, separately by type of stress contrast

Experiments 1 and 2	Stress pattern	Duration ^a		Mean F0 ^b		F0 range ^b		Mean amplitude ^c	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
10/01 pairs	10	157	151	266	200	60	73	1,951	1,217
10/01 pairs	01	127	185	225	238	43	76	1,366	1,803
201/01 pairs	201	140	128	232	231	50	37	1,678	1,515
201/01 pairs	01	141	219	243	243	42	71	1,481	1,665
10/201 pairs	10	190	123	252	201	77	34	1,954	1,445
10/201 pairs	201	143	118	218	213	37	49	1,907	1,255
<i>Experiment 3</i>									
10/01 pairs	10	175	129	277	241	77	77	1,510	830
10/01 pairs	01	139	187	227	260	44	43	948	1,596
201/01 pairs	201	149	134	250	235	52	32	976	868
201/01 pairs	01	147	214	250	260	52	49	1,059	1,526

Note: Stress pattern 10: primary stress on first syllable, unstressed second syllable (e.g., *OCtopus*). 201: primary stress on third syllable, secondary stress on first syllable, unstressed second syllable (e.g., *paraDIJS*). 01: primary stress on second syllable, unstressed first syllable (e.g., *paRAde*).

^aIn ms. ^bIn Hz. ^crms.

Procedure

Listeners were tested singly or in pairs in individual sound-attenuated cubicles, furnished with two response keys labelled JA ("yes") and NEE ("no"). They heard the auditory materials, upsampled to 20 kHz, over Sennheiser closed headphones and viewed the target words or nonwords on a high-resolution NEC Multisync II CRT monitor. Each trial began with a warning tone, followed by an auditorily presented sentence. The target became visible at the offset of the prime fragment and remained on the screen for 1,000 ms. Reaction times were measured from prime offset (i.e., target onset) with a time-out interval of 2,500 ms. The interstimulus interval was 3,450 ms.

Subjects were allocated to each of the four test versions in rotation. The data for 6 subjects were lost; 14 of the remaining subjects heard each of the test versions. They received written instructions to listen to the spoken sentences and look at the screen in front of them. As soon as a string of letters appeared on the screen, they had to decide immediately whether this was a real Dutch word or not and press the appropriate response key. The experiment began with the practice session, after which subjects had an opportunity to ask questions. The first and second halves of the experiment were then presented without a break. Timing and response collection were controlled by a personal computer running NESU experimental control software (see <http://www.mpi.nl/tools/nesu.html>).

Results and discussion

The correct response rate was high (95.8%). The mean RT for correct YES responses to word targets in the first half of the experiment was 588 ms, whereas the mean RT for the second half of the experiment was significantly faster (509 ms): $F_1(1, 52) = 138.84$, $p < .001$, $F_2(1, 19) = 84.38$, $p < .001$. This strong repetition priming effect also interacted with the

main effect of prime condition: $F_1(3, 156) = 4.95, p < .01$; $F_2(3, 57) = 7.4, p < .01$. Accordingly, joint analysis of the two halves would be unwise, and we therefore report the results from the first half experiment only. Mean RTs and errors for the stress-matching, stress-mismatching, and control prime conditions, respectively, are displayed in Figure 1. In the figure, the control conditions (which never differed significantly in any of the experiments in this study) have been merged, though a four-way comparison was maintained in the statistical analyses, so that targets could be compared after stress-matching versus control primes, and after mismatching versus control primes, within the same matrix sentences in each case.

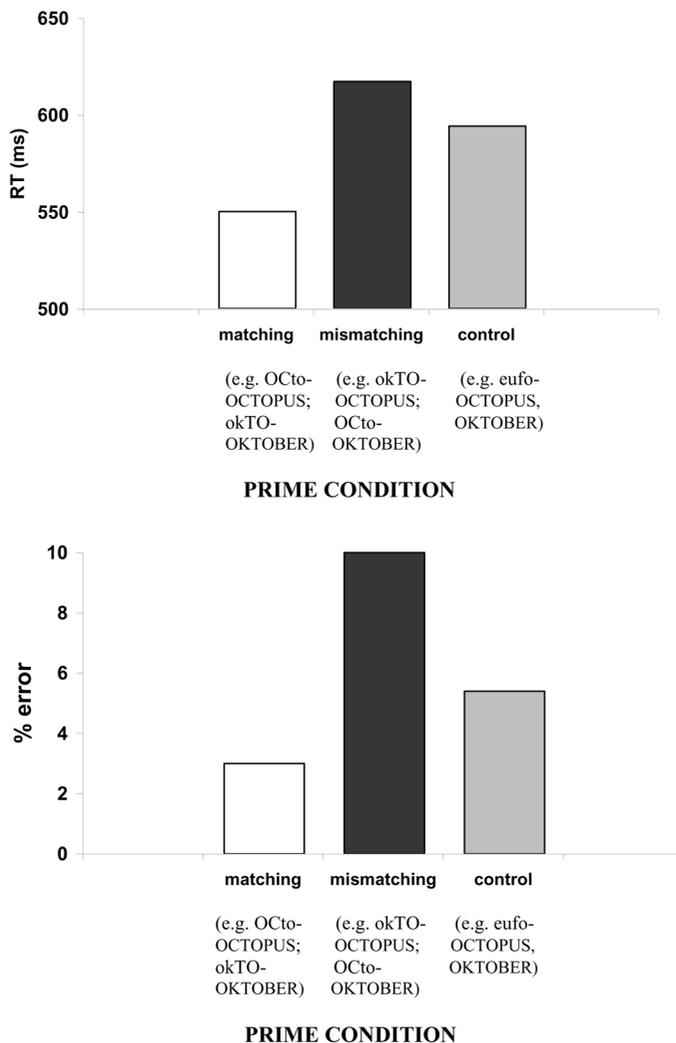


Figure 1. Mean lexical decision response times (RTs; top panel) and percentage errors (bottom panel) for the experimental targets in each of the three prime conditions of Experiment 1: matching stress, mismatching stress, control.

Analyses of variance (ANOVAs) were carried out on both the RT data and the error data, across subjects and across items separately. In the RT analysis, the main effect of prime conditions was highly significant: $F_1(3, 156) = 29.37, p < .001$, and $F_2(3, 57) = 24.36, p < .001$. Post hoc t tests revealed that RTs were significantly faster in the stress-matching prime condition (550 ms) than in the control prime condition (594 ms): $t_1(55) = 6.48, p < .001$; $t_2(19) = 6.24, p < .001$, and RTs in the mismatching condition (617 ms) were significantly slower than those in the control condition: $t_1(55) = 2.88, p < .01$; $t_2(19) = 3.9, p < .01$. We examined the power of these effects by tallying the number of subjects and items showing each effect; facilitation for stress-matching primes appeared for 85.7% of the subjects ($z = 5.21, p < .05$) and 85% of the items ($z = 2.91, p < .05$), while inhibition for stress-mismatching primes appeared for 66.1% of the subjects ($z = 2.27, p < .05$) and 75% of the items ($z = 2.01, p < .05$).

The effect of stress contrast type was not itself significant and did not interact with the effect of prime condition (all $F_s < 1$). Pairs with a primary stress contrast of the first versus the second syllable (e.g., *OCtopus-okTOber*) showed 56 ms of facilitation and 58 ms of inhibition; pairs with a second versus third syllable contrast (e.g., *paRAde-paraDIJS*) showed 51 ms of facilitation and 30 ms of inhibition; pairs with a first versus third syllable contrast (e.g., *DOMinee-domiNANT*) showed 45 ms of facilitation and 30 ms of inhibition.

Exactly the same pattern appeared in the error analysis, namely a significant main effect of prime condition: $F_1(3, 156) = 9.23, p < .001$, and $F_2(3, 57) = 10.36, p < .001$; post hoc t tests again revealed that error rates were significantly lower in the stress-matching prime condition (3%) than in the control prime condition (5.4%): $t_1(55) = 2.38, p < .02$, $t_2(19) = 2.67, p < .02$, while error rates in the mismatching condition (10%) were significantly higher than those in the control condition: $t_1(55) = 3.78, p < .001$, $t_2(19) = 4.18, p = .001$. Excluding ties, 74.3% of subjects ($z = 2.70, p < .05$) and 75% of items ($z = 1.75, p < .05$) had fewer errors after stress-matching than control primes, while 73.9% of subjects ($z = 3.1, p < .05$) and 81.25% of items ($z = 2.25, p < .05$) had more errors after mismatching than after control primes. The effect of stress contrast was again insignificant; pairs with a primary stress contrast of first versus second syllable showed a 3.5% facilitatory and a 4.2% inhibitory effect, pairs with a second versus third syllable contrast 1.7% facilitation and 4.5% inhibition, and pairs with a first versus third syllable contrast 2.4% facilitation and 5.9% inhibition.²

This experiment thus produced the same result as was found in the analogous study by Soto-Faraco et al. (2001) in Spanish: Prime fragments matching the target word both segmentally and in stress pattern (*OCto- OCTOPUS*) led to significantly faster response times, whereas prime fragments that were segmentally matching but suprasegmentally different (*OCto- OKTOBER*) produced inhibition. Thus Dutch listeners, like Spanish listeners, can efficiently make use of suprasegmental information to constrain lexical activation, even though their language also usually offers segmental correlates of the stress distinctions that the suprasegmentals convey. Moreover, different types of stress contrast were used equally effectively. As Table 1 shows, although the types of stress contrast differed in how they were suprasegmentally distinguished, each contrast offered listeners clear differences across the members of the experimental pairs. These results showed that listeners used these cues in each contrast

²In the second half of Experiment 1, the condition RT and error means were 480/1% (stress-matching prime), 521/3% (stress-mismatching prime), and 525/3% (control prime).

type and thus suggest that the reason that Cooper et al. (2002) found a different pattern of results for English should not be ascribed to the nature of the stress contrasts exemplified in the materials of that study.

In our next experiment we explore the question of how rapidly stress information can constrain lexical access. Cutler and Donselaar (2001) showed that Dutch listeners could make remarkably accurate judgements in an off-line task about the source of single-syllable fragments taken from minimal stress pairs such as *VOORnaam* (“first name”)–*voorNAAM* (“respectable”)—that is, single syllables differing only in stress level in their source word. Cooper et al. (2002) found that Dutch listeners in fact outperformed English listeners in making stress judgements about single syllables from English pairs such as *MUSic*–*muSEum*. This suggests that even a single syllable may provide enough stress information to distinguish between lexical candidates, so that a Dutch listener can, for example, after one syllable appropriately adjust activation of *octopus* versus *oktober*.

However, it may also be the case that off-line results provide only a poor indication of what information can be rapidly used in online lexical activation. We have argued that the competition effect reflects initial availability of both candidates (e.g., *octopus* and *oktober*), the ensuing competition between them being then resolved by stress information favouring the one over the other. It may be that the initial simultaneous availability of both candidates is not resolvable until after the first syllable—that is, that only the comparison of two syllables can provide definitive distinctive stress information. In that case we should observe equivalent facilitation for both candidates to the initial syllable alone; at the end of the first syllable a listener may not in fact be able to tell whether a spoken word will become *octopus* or *oktober*.

Accordingly in Experiment 2 we investigate whether single-syllable prime fragments will selectively prime stress-matching candidates. In this test we use the Experiment 1 materials, for which we have already ascertained bisyllabic identity-priming effects. The examination of monosyllabic fragments also constitutes a further advance on the investigations of Soto-Faraco et al. (2001), since in their stress study only bisyllabic fragments were used.

EXPERIMENT 2

Method

Participants

A total of 60 native speakers of Dutch from the same population as that in Experiment 1 were tested; none had participated in Experiment 1. Again, all had normal hearing and normal or corrected-to-normal vision; again, they were paid a small sum for participating.

Materials and procedure

The materials from Experiment 1 were further truncated such that only the initial syllable of the prime word (e.g., *OC-*, *ok-*) remained. The practice and filler primes were also truncated. Otherwise the Experiment 1 materials were unchanged. The procedure was also as that in Experiment 1, except that the instructions were adapted to give examples with one-syllable rather than two-syllable fragments. The data from 4 subjects were lost due to technical reasons; 14 of the remaining subjects heard each of the four test versions.

Results and discussion

The correct response rate was once again very high (97.1%). The mean RT for correct YES responses to word targets in the first half of the experiment was 551 ms, whereas the mean RT for the second half of the experiment, in which the targets occurred for the second time, was again speeded by repetition priming (501 ms). As in Experiment 1 this difference was significant: $F_1(1, 52) = 123.32, p < .001$; $F_2(1, 19) = 46.59, p < .001$, and the interaction of the effect with that of prime condition was also significant across subjects: $F_1(3, 156) = 2.68, p < .05$; $F_2(3, 57) = 1.18$. As for Experiment 1 we therefore report only the first half. Mean RTs and errors for stress-matching, stress-mismatching, and control prime conditions are displayed in Figure 2.

ANOVAs were carried out on both the RT data and the error data, across subjects and across items separately. No effects were significant in the error analysis. In RTs, the main effect of prime conditions was significant: $F_1(3, 156) = 4.21, p < .01$; $F_2(3, 57) = 3.51, p = .02$. Post hoc t tests showed that RTs were significantly faster in the stress-matching prime condition (540 ms) than in the control prime condition (559 ms): $t_1(55) = 2.06, p < .05$, $t_2(19) = 2.49, p < .025$, but RTs in the mismatching condition (555 ms) did not differ from those of the control condition. Facilitation for stress-matching primes appeared for 66.1% of subjects ($z = 2.27, p < .05$) and 85% of items ($z = 2.91, p < .05$).

The effect of stress contrast was again not significant and again did not interact with the effect of prime condition ($F_s < 1$). No condition showed more than 6 ms inhibition; facilitation was 18 ms for the six pairs with a primary stress contrast of the first versus the second syllable (e.g., *OCtopus-okTOber*), 28 ms for the 11 pairs with a second versus third syllable contrast (e.g., *paRAde-paraDIJS*), and only 1 ms for the three pairs with a first versus third syllable contrast (e.g., *DOminee-domiNANT*); note that the first syllables of these three pairs contrast primary versus secondary stress.³

This experiment has thus shown that monosyllabic fragments can indeed lead to selective activation of stress-matching candidates. The experiment produced clear evidence that stress-matching primes produce facilitation while stress-mismatching primes do not; only the contrast between primary and secondary stress was not exploited on the basis of a single syllable. Any contrast between a syllable that was unstressed versus stressed (either with primary or with secondary stress) was, however, immediately used by listeners.

In this experiment we did not observe inhibition evidence for competition. This, we suggest, is because although the single syllable fragments carried sufficient information to signal stress, they still could not resolve the competition process to the necessary extent. The competitor set invoked by a monosyllable is too large to allow decisive competition; for *oc-*, for instance, the set includes, besides *octopus* and *oktober*, also *OKsel* (“armpit”), *ocTROOI* (“patent”), *ocTAAF* (“octave”), *occuPEren* (“occupy”), and many more. Some of these can be ruled out on the basis of stress information (so their activation drops away), but those remaining are still subject to sufficient competition from rivals that they cannot muster the amount of activation necessary to exert strong inhibition. Specifically, while *OC-* will support *octopus*, it will also support *oksel* (as well as perhaps *occuperen* with secondary stress on

³In the second half of Experiment 2, the condition means were 496 ms/4.3% error (stress-matching prime), 493 ms/3.2% error (stress-mismatching prime), and 513 ms/4.7% error (control prime).

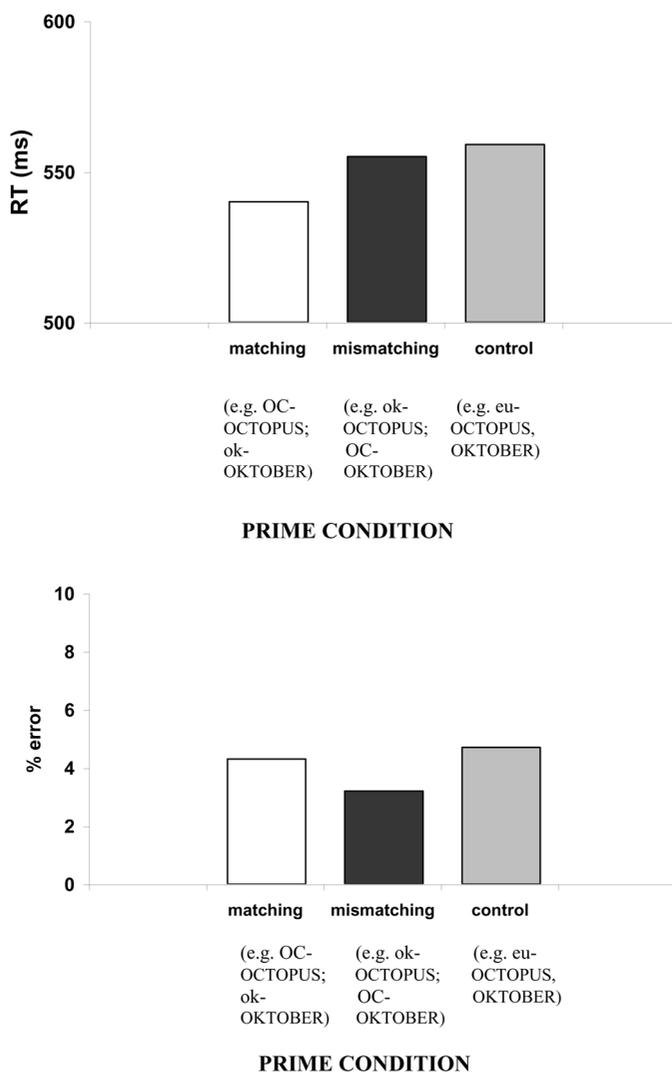


Figure 2. Mean lexical decision response times (RTs; top panel) and percentage errors (bottom panel) for the experimental targets in each of the three prime conditions of Experiment 2: matching stress, mismatching stress, control.

the first syllable), and *ok-* will support not only *oktober* but also *octrooi* and *oktaaf*. Despite the absence of inhibition, however, the clear and significant difference between the stress-matching and mismatching prime conditions suffices to demonstrate that listeners make use of stress information in only a single syllable.

Experiments 1 and 2 have therefore convincingly shown that Dutch listeners use the suprasegmental correlates of stress in the online resolution of lexical activation and competition. The widespread availability of segmental correlates of stress in Dutch does not render

the use of suprasegmental information redundant. Moreover, different kinds of stress contrast can be equally usefully exploited—at least when both of the first two syllables are available—so that we can assume that even the limited range of minimal pair contrasts offered by English would provide listeners with effective information. The fact that Cooper et al. (2002) found no evidence of inhibition from stress mismatch in English needs further explanation than simple reference to stress contrast type.

As described in the Introduction, previous findings from English had motivated the claim that English listeners do not make use of suprasegmental cues to stress in word recognition. However, these findings were mostly based on off-line measures such as percentage correct word recognition (Bond & Small, 1983; Slowiaczek, 1990; Small et al., 1988) or acceptability judgements (Slowiaczek, 1991; see also Fear, Cutler, & Butterfield, 1995). The one on-line study of this issue in English (Cutler, 1986) used cross-modal priming, but the experimental target words in that study were not the same as the prime words but instead associatively related to them.

A recent study of lexical activation by Norris et al. (2003) reported nine cross-modal priming experiments comparing facilitatory effects from identical versus associatively related primes. On the basis of the variable patterning that they observed in associative priming effects, Norris et al. argued that the phonological representations activated by speech input, and potentially tapped in identity priming experiments, are distinct from the conceptual representations activated in the course of utterance interpretation. There is no necessary carry-over from activation of a phonological representation to activation of a conceptual representation. It is therefore possible that suprasegmental information is relevant at only one of these processing levels and not at the other. Since evidence from three languages—Dutch in the present Experiments 1 and 2, Spanish in Soto-Faraco et al.'s (2001) Experiment 1, and English in the study of Cooper et al. (2002)—has now supported the relevance of suprasegmental information in the phonological representations tapped by identity priming, the contrast with previous results from English may arise from a comparison with tasks tapping conceptual representations. In other words, the on-line experiments in question may not have tapped into the processing level at which suprasegmental constraints play a role.

No study has previously compared identity priming and associative priming with the same stress-varying materials. In Experiment 3 we undertake this comparison. As in Experiment 1, we present truncated bisyllabic fragments of pairs such as *paRAde-paraDIJS* and measure response time for lexical decision on visually presented targets. The targets are, however, not the same as the prime words (e.g., PARADIJS), but are associatively related to them (e.g., HEMEL, “heaven”). According to Norris et al.'s (2003) proposal, the conceptual representations tapped by this task are not necessarily activated with the phonological representations tapped in identity priming. Thus we may observe different results from Experiment 1: either no effect at all of stress variation (so that the differing results from experiments with English simply reflect unsuitability of conceptual tasks for investigating stress), or selective effects (e.g., facilitation but no inhibition, reflecting carry-over of activation from phonological to conceptual levels by successful candidates only). Finally, response modulation by both stress match and mismatch as in Experiment 1 would counter Norris et al.'s proposal by suggesting that conceptual representations are indeed directly responsive to suprasegmental variation; in that case, too, no further light would be shed on the asymmetry between the earlier and the recent English results.

EXPERIMENT 3

Method

Participants

A total of 80 native speakers of Dutch from the same population as that in Experiments 1 and 2 were tested; none had participated in those experiments. Again, all had normal hearing and normal or corrected-to-normal vision; again, they were paid a small sum for participating.

Materials

The same extended pool of stress pairs was tested for the availability of associates in the Dutch association norms collected by Marslen-Wilson and Zwitserlood (1989) and de Groot (1980). The exact selection used in Experiments 1 and 2 could not be used in this experiment because not all of those items had clear associates. A selection of 24 pairs was made for Experiment 3, including 13 pairs that also occurred in Experiments 1 and 2, and 11 new pairs. The average correct response rate received by the Experiment 3 set in the stress judgement pretest of Experiment 1 was 76%. In 7 pairs the primary stress contrast involved first and second syllables, and in 17 pairs the second and third syllables. A control prime was again assigned to each stress pair. The 24 stress pairs are listed in the Appendix.

Each word's associate was used as a target lexical decision item, and a matched control target word was also chosen for each. For example, the associate for *parade* was OPTOCHT ("procession"), and its control was WIEROOK ("incense"), while the associate for *paradijs* was HEMEL ("heaven"), and its control was TANTE ("aunt"). Facilitatory priming was checked via a visual lexical decision experiment in which RT to the proposed associate targets was measured when the immediately preceding word was the proposed related prime word or the proposed control prime. In this experiment, involving 24 participants from the same subject population as that used in Experiments 1 and 2, mean RT to the targets was 552 ms when they were preceded by related primes and 576 ms when they were preceded by control primes, a significant facilitatory effect: $F_1(1, 22) = 12.98, p < .005$; $F_2(1, 47) = 10.46, p < .005$.

A new recording was made by the same speaker as that used for Experiment 1, with the primes arranged in the same way at the ends of nonconstraining sentences. The sentences were the same as those used in Experiment 1 plus four further sentence pairs from the pretest set. Again the sentence-final words were truncated, as in Experiment 1 after the second syllable. Measurements were made as before, and the mean values are also listed in Table 1.

Four sets of materials were constructed. Because the addition of control targets meant that Experiment 3 was longer than Experiments 1 and 2, no repetitions of targets occurred, in order to avoid subject fatigue. There were in this case 16 possible prime-target pairings for each stress pair. Thus *paRA(-de)* could occur with the associated target OPTOCHT, its control target WIEROOK, its stress pair's target HEMEL, and that target's control TANTE; the stress pair *para(-DIJS)* could also occur with these four targets. Also the control prime for this pair (*grot*, "cave") could occur in each of the two neutral sentences with each of the four targets. Four of these possible trials occurred in each of the materials sets; each materials set contained each of the four targets, two with experimental and two with control primes, and although no prime or target occurred twice in a materials set, the nonconstraining sentences did occur twice (once with an experimental, once with a control prime).

Procedure

The procedure was as that in Experiment 1, except that the instructions were adapted to give examples with prime-target pairings appropriate for the current experiment. A total of 10 listeners heard each materials set.

Results and discussion

The correct response rate was again high (97.5%). The mean RT for correct YES responses to word targets was 564 ms. Mean RTs and errors for experimental and control targets as a function of prime condition are displayed in Figure 3.

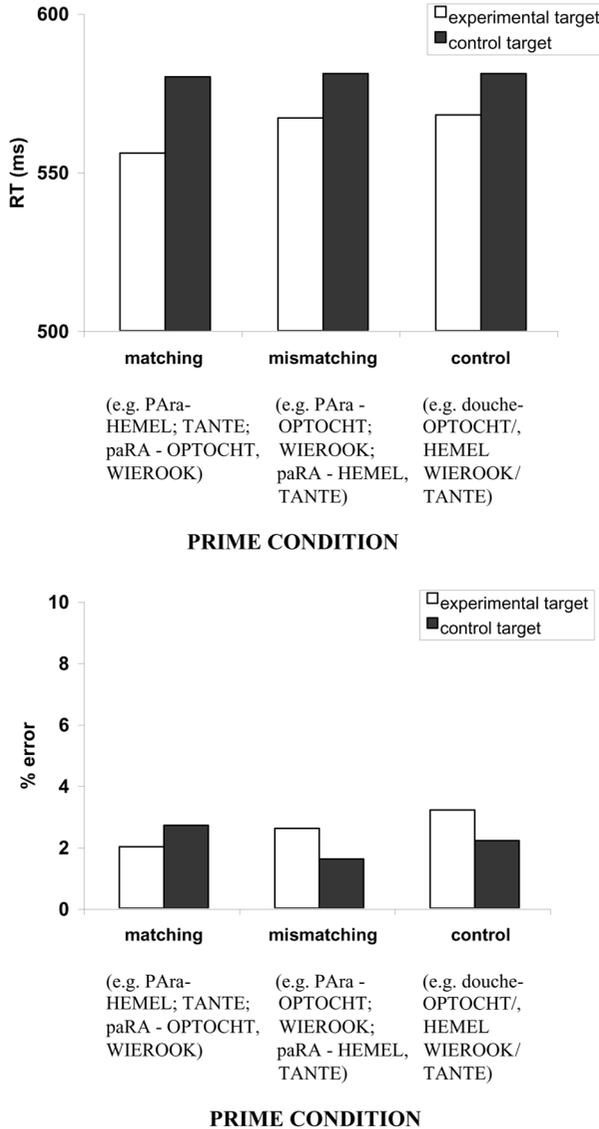


Figure 3. Mean lexical decision response times (RTs; top panel) and percentage errors (bottom panel) for the experimental and control targets in each of the three prime conditions of Experiment 3: matching stress, mismatching stress, control.

ANOVAs were again carried out on both the RT and error data, across subjects and items separately. This experiment involved a double control design, allowing both types of comparison used in associative priming studies (Tabossi, 1996), namely of related targets (OPTOCHT, HEMEL) with unrelated control targets (WIEROOK, TANTE), and of experimental targets after matching (*paRA*–OPTOCHT, *para*–HEMEL), mismatching (*paRA*–HEMEL, *para*–OPTOCHT), and control primes (*douche*–OPTOCHT, *douche*–HEMEL). Since the latter is the type of comparison carried out in Experiments 1 and 2, it is also used here, although Figure 3 also includes the means for the unrelated control targets.

The main effect of prime condition was significant across subjects: $F_1(3, 228) = 3.82$, $p < .01$, but was not significant across items ($F_2 < 1$); the main effect of stress contrast was not significant; there were no interactions. However, to enable direct comparison with the preceding experiments we again performed t tests, revealing one significant effect: across subjects, faster RTs to experimental targets preceded by stress-matching versus control primes, $t_1(79) = 3.29$, $p < .01$. We tallied the number of subjects and items showing the predicted effects, revealing that a majority of subjects and items showed facilitation for stress-matching primes (subjects 60%; $z = 1.68$, $p < .05$; items 57.5%), and inhibition for stress-mismatching primes (subjects 54.17%, items 52.08%).

In the errors, the main effect of prime condition was again significant across subjects only, $F_1(3, 228) = 4.71$, $p < .01$; $F_2(3, 141) = 1.25$, and there were no effects of stress contrast. The t tests again revealed just one significant comparison, namely fewer errors to experimental targets after stress-matching versus control primes: $t_1(79) = 2.97$, $p < .01$. Some subjects and just over half the items had no errors at all, but excluding ties, errors were fewer in the stress-matching condition than in the control for 82.86% of subjects ($z = 2.7$, $p < .05$) and 53.3% of items, while the stress-mismatching and control conditions showed no consistent effect (52.9% of subjects and 47.8% of items more errors after stress-mismatch). We conducted items analyses on only the subset of 13 pairs common to all three experiments; these showed in Experiments 1 and 2 the significant effects observed for those items sets in total, but in Experiment 3 no significant differences across conditions.

In a subsidiary items analysis, we compared associative priming for those of our items where the presented fragment uniquely constrained the word's identity, versus those that were not unique. Although our items involved no large competitor sets, and many competitors were low in frequency, the very strict constraints on item selection had meant that our item pairs differed in whether they were fully unique at fragment offset. Thus, for instance, *kasTA*- can only become *kastanje*, as no other Dutch word begins *kasTA*-, but for other words there was sometimes a single competitor (e.g., *dissident* “dissident”, given *disci*- from *discipline*) or even more than one (e.g., for *Ali*- from *alibi*, both *alias* “alias” and *alikuik* “periwinkle”). An items analysis involving this added factor revealed that it had no main effect, but did interact with the effect of prime condition: $F_2(1, 46) = 4.41$, $p < .05$. For the 25 items without competitor, RTs to experimental targets after stress-matching primes were faster (569 ms) than after control primes (596 ms): $t_2(24) = 2.24$, $p < .04$. RTs for these items after stress-mismatching primes did not differ from RTs after control primes. For the 23 items with competitor, mean RTs after matching, mismatching, or control primes were never significantly different.

This experiment did not support modulation of associates by suprasegmental variation. In contrast to Experiments 1 and 2, in which stress match effects were always robust across subjects and items, such effects appeared here only for the subset of items that supported a unique

interpretation; inhibitory effects of stress mismatch were totally absent, although these too had been robustly exercised by bisyllabic fragments in Experiment 1. It thus appears that associative priming is not tapping the same representations as those activated in identity priming such as we used in Experiments 1 and 2, nor are the representations tapped by associative priming directly modulated by suprasegmental variation. This suggests that results from identity-priming and associative-priming experiments in English are indeed not comparable. We return to the task issue and its implications below.

GENERAL DISCUSSION

The three experiments we have reported motivate the following conclusions. First, stress information constrains lexical activation even when the stress contrasts of the language in question are in general also marked by segmental variation. Second, the exploitation of suprasegmental information in lexical processing begins as soon as relevant acoustic information is available, namely within a single syllable. Third, word fragments exercise direct facilitatory and inhibitory constraint on activation of phonological representations participating in the process of competition for lexical selection, but no such direct constraint on conceptual representations.

In the Introduction we outlined the variation that is possible in the realization of lexical stress across languages. In particular, stress languages differ in whether stress placement is fixed or may vary across words; only in the latter case is stress placement potentially available to distinguish one word from another. Within such free-stress languages, there is further opposition between languages that do not allow vowel reduction and hence realize stress differences via suprasegmental means alone (Spanish, for example) versus languages (such as Dutch or English) that do allow vowel reduction, in which case vowel quality variations accompany variation in stress.

Listeners exploit incoming information in speech signals in a continuous manner, making use of cues as soon as they become available in order to modulate the activation of potential candidate words that have received some support from the speech signal. Segmental information becomes available more rapidly than suprasegmental information. In a consonant-vowel (CV) sequence, for example, the transition from the consonant to the vowel suffices to enable listeners to identify the vowel even if all steady-state vowel periods have been removed (Strange, 1989). Suprasegmental cues to stress are realized primarily in the duration of the vowel, the intonational movement expressed on the vowel, and the pitch height and amplitude, again chiefly of the vowel. Duration clearly cannot be apprehended until the vowel has been presented in full, and pitch judgements also require more time than vowel quality judgements, as experimental evidence from a variety of tasks has demonstrated (Cutler & Chen, 1997; Robinson & Patterson, 1995).

Since segmental (vowel quality) information may be exploited in the modulation of lexical activation at a point at which suprasegmental information is not yet available, it is not clear that listeners would actually need to draw upon suprasegmental information in lexical processing to any great extent in languages that allow segmental concomitants of stress. It is a striking fact that such languages very rarely make use of solely suprasegmental distinctions between words; pairs such as Dutch *VOORnaam-voorNAAM* or English *TRUSty-trusTEE* are very rare indeed (fewer than 20 pairs in each language).

Evidence from studies in Dutch over recent years, involving many types of task, definitely indicates that suprasegmental information is not ignored in lexical processing. Thus Dutch listeners achieve high accuracy in assigning truncated syllables to one of two words containing a segmentally identical but differently stressed syllable (e.g. *si-* from *SIlo*, “silo”, versus *siGAAR*, “cigar”; van Heuven, 1988), or to one of the members of a minimal stress pair such as *VOORnaam-voorNAAM* (Cutler & Donselaar, 2001). Mis-stressed words are harder to recognize when truncated (van Heuven, 1985; Van Leyden & van Heuven, 1996), and they impair performance in a semantic judgement task (Cutler & Koster, 2000; Koster & Cutler, 1997). There is no repetition priming from one member of a minimal stress pair to a later presentation of the other (Cutler & Donselaar, 2001); this indicates selective recognition.

However, tasks involving off-line decisions (such as identification of truncated words) or indirect measures of initial activation (e.g., repetition priming with intervening items, or judgement of semantic relatedness) do not assess the speed with which suprasegmental information can be evaluated. Prior to the present study only two published experiments had investigated the contribution of suprasegmental structure in lexical activation in Dutch. These were two of Cutler and Donselaar’s (2001) experiments: first, the demonstration that a mis-stressed fragment (e.g., *MUzee*) did not produce as much inhibitory competition as a correctly stressed fragment (e.g., *muZEE*, compatible with *museum*, and hence inhibiting detection of the word *zee* embedded in the fragment); and second, the corroboratory finding that recognition of MUSEUM was indeed more effectively facilitated by prior presentation of the matching than of the mismatching fragment. As we pointed out in the Introduction, though, the fragments used in these experiments related to only one longer word, with which they were either compatible or incompatible. They did not crucially distinguish between words sharing segmental but not suprasegmental overlap. Only cases of this kind can test how rapidly suprasegmental information can modulate the activation of lexical candidates. Such cases were tested in the present study, and we indeed observed effects of stress match versus mismatch on activation of word candidates. Recognition of OKTOBER was significantly facilitated by prior presentation of the matching fragment *okTO-*, but significantly inhibited by prior presentation of the mismatching fragment *OCto-*. Furthermore, contrasts of either primary or secondary stress with unstressed syllables were equally effective in constraining activation.

A very similar result appeared in our second experiment, in which we presented only initial syllables as primes. The results again showed a clear effect of stress match versus mismatch. Just the first syllable of *OCtopus* or *okTOber* was enough to facilitate the matching word form. This clearly showed that listeners were processing the suprasegmental cues to stress in just a single syllable. Again, listeners could evaluate either primary or secondary stress contrasts with an unstressed syllable. This result confirms that the abilities of Dutch listeners to exploit the cues in a single syllable in off-line forced-choice tasks either in Dutch (Cutler & Donselaar, 2001; van Heuven, 1988) or in English (Cooper et al., 2002) also carry through to on-line lexical processing. Note that all these findings contrast with one previous report, by Jongenburger and van Heuven (1995), that listeners making free guesses regarding the identity of truncated words could only use stress pattern once the initial syllable plus at least part of the vowel of the second syllable had been heard. (By contrast, in a similar free-guessing gating study by Cutler & Otake, 1999, Japanese listeners produced 80% and more correct accent patterns given no more than half the initial syllable.) Our study clearly

shows that the suprasegmental information in a single initial syllable can be exploited in the processing of Dutch words, just as it is in the processing of Japanese words; moreover, this exploitation plays a role in on-line recognition.

Thus the evidence from Dutch has clearly shown that suprasegmental information can be fully exploited in lexical activation in a language in which stress also has segmental correlates, and that different types of stress contrast can be exploited equally effectively; the differing results from previous identity-priming studies in Spanish (Soto-Faraco et al., 2001) and English (Cooper et al., 2002) cannot be ascribed either to the existence of segmental correlates of stress in English (but not Spanish) or to the restrictions of type of stress contrasts that could be assessed in such an experiment in English. Instead, the English listeners, in producing no evidence of inhibitory competition effects of stress mismatch given bisyllabic fragments, simply appear to make less efficient use of the suprasegmental information than do either Spanish or Dutch listeners. Compatible with this is Cooper et al.'s finding that non-native Dutch listeners were actually better at judging (off-line) the source of monosyllabic English fragments than native English-speaking listeners were. A reason for the reduced use of suprasegmental cues by English listeners may be that the processing of such information produces less benefit in English than it does in either Spanish or Dutch. In both of the latter languages, within-word sequences of syllables with full vowels contrasting in stress are common. In English, such sequences of syllables with full vowels rarely occur; most syllables with full vowels are juxtaposed to syllables with reduced vowels. It may be that it is only in stress-varying sequences of syllables with full vowels that exploiting suprasegmental cues to stress pattern and hence to word identity produces substantial payoff in terms of increased recognition efficiency. Cutler, Dahan, and Donselaar (1997), reviewing evidence on the role of prosodic structure in language processing, argued that the use of prosodic information in processing depends on the information it gives the listener. In word recognition, accordingly, listeners are unlikely to rely on any dimension of variation that yields little in the way of crucially distinctive information regarding word identity.

Like segmental information, suprasegmental information modulates lexical activation by favouring matching words and disadvantaging mismatching words; where the information it provides is in a position to decide the outcome of inter-word competition, a high level of activation of the favoured word results in inhibition of the mismatched word. This was the result we clearly saw in Experiment 1, and the same result was observed in Spanish by Soto-Faraco et al. (2001). Where multiple candidates remain in the competition, and no single candidate can achieve a sufficiently high level of activation to inhibit rivals effectively (as in Experiment 2), the activation of the mismatched word form drops, but not to a point at which inhibition of responses in comparison with control words would be observed. This pattern of results is captured by models of spoken-word recognition involving multiple simultaneous activation of word candidates and competition between them.

The results from our identity priming experiments thus indicate that suprasegmental information is relevant for the phonological representations involved in this activation stage of word recognition. However, the pattern of results manifested in our first two experiments, and especially in Experiment 1, contrasted with the results of Experiment 3 with associative priming. Here, we only observed evidence of facilitation of conceptual representations by the bisyllabic word fragments we presented when a unique word was matched. As discussed above, Norris et al. (2003) argued that phonological and conceptual representations are

distinct and that activation of a phonological representation does not necessarily entail that activation of a conceptual representation will ensue. The conceptual representations activated by a given input depend on the utterance and indeed discourse context as a whole. The differing pattern of results that we found for different types of target with essentially the same auditory primes is compatible with Norris et al.'s proposal and further supports the suggestion that asymmetry between earlier results from English with associative priming, and recent results from English with identity priming, is not paradoxical, but simply results from contrasting tasks that tap into different levels of processing.

We should point out that this does not mean that associative priming is unsuited as a task for studying spoken-word recognition. Rather, what is now called for is attention to exactly which spoken inputs activate phonological representations, and which inputs activate conceptual representations. One of the conditions under which Norris et al. (2003) observed reliable associative priming was when prime words were presented in isolation—that is, when the prime word itself constituted the entire utterance. In our Experiment 3, the prime fragments were presented as the termination of short sentences—that is, in an utterance context—but the sentences were semantically (and phonologically) nonconstraining, so that conceptual contribution from the sentence context would be minimal. On the proposal of Norris et al., this should create appropriate conditions for appearance of associative priming effects. Indeed, our Experiment 3 did not produce null results; there were facilitatory effects of stress match across the whole subject set and across those items supporting a unique candidate.

How should this pattern be interpreted? First, it is obvious that this is not the same as the effects of competitor set observed in Experiment 1. In that study, as in the Spanish experiments of Soto-Faraco et al. (2001), competition was observed via inhibition as a result of minimal mismatch between prime and target. That pattern of results in Experiment 1 was always robust across items, although the items of Experiment 1 manifested the same variability in further competitor set structure as did the items of Experiment 3. In Experiment 3, though, the extended competitor set seems to have been crucial in determining whether associative priming occurred. For word fragments with no competitor—that is, words that were uniquely determined by the presented fragment—facilitatory (but only facilitatory) effects could be exercised upon associatively related words.

We suggest that the pattern should be interpreted as follows. Suprasegmental information is used in the activation of phonological representations that participate in the competition process involved in lexical recognition. It is used in the same way as segmental information—a match facilitates compatible candidates, and a mismatch disadvantages incompatible candidates. Strongly supported lexical candidates, and certainly winning lexical candidates, feed facilitatory activation to higher level lexical processing where conceptual representations may be activated. Phonological information, segmental or suprasegmental, is not distinctive at this level; only facilitation is passed forward from the phonological to the conceptual level. Conceptual representations associated with the activated lexical node may be activated where appropriate for the utterance context. A prime that is a winning candidate will exercise facilitatory effects on words associated to these activated conceptual representations, but a prime that is a losing candidate will never directly inhibit associates; phonological mismatch is relevant only for phonological representations.

Interestingly, it is the use of fragment priming in the present study, plus the comparison of identity priming and associative priming by the same fragmentary materials, which

has made this pattern clear. Norris et al. (2003) convincingly demonstrated that phonological and conceptual representations are distinct, and that activation of the first does not necessarily lead to activation of the second. Their experiments used whole-word primes, which meant that the listener's word recognition process could always yield a winning competitor. Under these circumstances they could examine the characteristics of the utterance context that were more versus less conducive to associate activation. With our word-fragment materials, the unique winner condition was not always met. Thus we could observe the effects of this condition; where there indeed was a winning competitor on the basis of the phonological input, facilitation of associates could be observed, but where the prime fragment was insufficient to uniquely determine a winning candidate, no facilitation appeared. We cannot know from this finding whether only a winning candidate can produce sufficient facilitation from a fragment prime to activate associates, or whether this can be achieved by a criterial level of support for any given candidate; however, in the case of a winning candidate associate facilitation is definitely possible. Further, although in Experiment 1 the same bisyllabic fragments used in Experiment 3 could be seen to exercise inhibitory effects as well, at no time was inhibition observed in Experiment 3, because at the conceptual level no phonological competitors are activated; only conceptual representations are relevant, and these are only activated for words with strong support at the phonological level.

Our study has thus further illuminated the distinction between activation of phonological representations and activation of conceptual representations in speech comprehension; it is clear that the role of lexical stress in lexical recognition is confined to the former, namely to the level at which competition between word candidates takes place. At that level, we have shown, listeners make rapid and effective use of suprasegmental information about stress distinctions that differentiate between words. Even in a language in which stress distinctions between words often involve segmental as well as suprasegmental variation, the suprasegmental information is exploited by listeners with great efficiency.

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APPENDIX

Word pairs used in the experiments, with English glosses. Upper case denotes primary word stress placement.

Pairs used in Experiments 1 and 2 only:

OCtopus (octopus) okTOber (october); FYsicus (physicist) viSite (visit); CAvia (cavy) kaviAAR (caviar); DOMinee (pastor) domiNANT (dominant); MEdition (medium) mediCIJN (medicine); poLIitie (police) poliTIEK (politics); dipLOma (diploma) diploMAAT (diplomat)

Pairs used in Experiments 1–3:

ALbatros (albatros) alBANier (albanian); Alibi (alibi) aLInea (paragraph); AUditor (auditor) auDIitie (audition); Opium (opium) oPIinie (opinion); kaBIine (cabin) kabiNET (cabinet); saLAmi (salami) salaMANder (salamander); paRAde (parade) paraDIJS (paradise); diSCIpel (disciple) disciplINe (discipline); eTAge (storey) etaLAge (display case); kaNArie (canary) canaPE (sofa); kasTAnje (chestnut) castagNETten (castanets); proJECtor (projector) projecTIEL (projectile); triBUne (rostrum) tribuNAAL (tribunal)

Pairs used in Experiment 3 only:

DECibel (decibel) deCisie (decision); SYLlabus (syllabus) sylLAbe (syllable); TERrier (terrier) terRIine (terrine); maRIine (navy) mariNAde (marinade); canTAte (cantata) canthaREL (chanterelle); koLONie (colony) koloNEL (colonel); dyNAmo (dynamo) dynaMIET (dynamite); comMUnie (communion) kommuNIST (communist); forMUle (formula) formuLIER (form); kaRAte (karate) karaMEL (caramel); triANgel (triangle) triatLON (triathlon)