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The Syllabic Structure of Spoken Words: Evidence from the Syllabification of Intervocalic Consonants*

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ABSTRACT

A series of experiments was carried out to investigate the syllable affiliation of intervocalic consonants following short vowels, long vowels, and schwa in Dutch. Special interest was paid to words such as *letter* ['lɛtər] "id.," where a short vowel is followed by a single consonant. On phonological grounds one may predict that the first syllable should always be closed, but earlier psycholinguistic research had shown that speakers tend to leave these syllables open. In our experiments, bisyllabic word forms were presented aurally, and participants produced their syllables in reversed order (Experiments 1 through 5), or repeated the words inserting a pause between the syllables (Experiment 6). The results showed that participants generally closed syllables with a short vowel. However, in a significant number of the cases they produced open short vowel syllables. Syllables containing schwa, like syllables with a long vowel, were hardly ever closed. Word stress, the phonetic quality of the vowel in the first syllable, and the experimental context influenced syllabification. Taken together, the experiments show that native speakers syllabify bisyllabic Dutch nouns in accordance with a small set of prosodic output constraints. To account for the variability of the results, we propose that these constraints differ in their probabilities of being applied.

INTRODUCTION

Dutch has a relatively complex syllable structure, which allows for a large number of consonant clusters in both onset and coda. In a lexico-statistical investigation, Schiller, Meyer, Baayen, and Levelt (1996) identified 34 syllable types differing in CV-structure (e.g.,

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CVC, CVVC, CCVV, etc.) in the Dutch word form lexicon of the CELEX database.[1] Nevertheless, there are some constraints on Dutch syllable structure. One constraint that has been proposed is that short (lax) vowels do not occur in open syllables (Booij, 1995; van der Hulst, 1984; Kager, 1989; Trommelen, 1984). The same is claimed for other Germanic languages, for instance English (Crompton, 1981; Giegerich, 1992; Lass, 1976; Pulgram, 1970) and German (Ramers, 1988, 1992; Vennemann, 1970, 1982, 1986, 1994; Wiese, 1988, 1996). One argument for this claim is of distributional character. Short vowels rarely occur in word-final position or in hiatus (prevocalic) position; the only exceptions are interjections such as *bah* [bɑ], *joh* [jɔ], or *beh* [bɛ].

Furthermore, there is an argument from stress assignment implying that short vowels are not allowed in open syllables. The Dutch stress system is a mixture of a Germanic initial stress pattern, a French final stress pattern, and a Latin penultimate stress pattern (Booij, 1995). Trisyllabic words generally have antepenultimate stress (e.g., *lucifer* ['ly.si.fɛr] "match") unless the penultimate syllable is closed, that is, heavy, and attracts the stress (as in *elektron* [e.'lɛk.trɔn] "electron"). Adapted foreign words also obey this rule in that they often change their stress pattern (e.g., English *badminton* ['bæd.mɪn.tən] → [bɑt.'mɪn.tɔn] in Dutch), which shows that the rule is quite strict. There are, however, some polysyllabic word forms such as "Armageddon" that also have stress on the penultimate syllable (i.e., [ɑr.mɑ.'gɛ[d]ɔn], examples from Kager, 1989)[2] instead of the antepenultimate syllable. The penultimate syllable of these words has a short vowel and a single intervocalic consonant following that short vowel. If the penultimate syllable were open, it could not bear the stress. Therefore, it is assumed that the penultimate syllable is closed by the intervocalic consonant, which forms the onset of the following syllable at the same time (Kager, 1989). As a corollary of that, single intervocalic consonants following short vowels are generally assumed to be ambisyllabic (see the discussion on ambisyllabicity below).

Dutch schwa, however, although phonetically short, can occur at the end of a word (e.g., *sonate* [so.'na.tə] "sonata," *pauze* ['pɑʊ.zə] "pause"), just like the long vowels. To account for the distribution of Dutch schwa, Booij (1995) argues that it occupies two positions, so-called X-slots, on the timing tier (see Halle & Mohanan, 1985 and Levin, 1985). This may be counter-intuitive given that schwa is phonetically short. Furthermore, schwa behaves differently from both short and long vowels in that it can never bear lexical stress, suggesting that it forms a class by itself.

The difference in the phonological behavior of short and long vowels is reflected in the Dutch orthographic system, which is phonologically relatively transparent (see Booij, Hamans, Verhoeven, Balk, & van Minnen, 1979). Short vowels are always spelled as a single letter. Long vowels are spelled as single letters in open syllables (including word-final position) and as two letters in closed syllables (e.g., *kilo* ['ki.lo] "id." vs. *loot* [lot] "shoot;" see Booij, 1995). To indicate the phonological vowel length in syllables with a short vowel (short vowel syllables hereafter), single intervocalic consonants are spelled as geminates, i.e., double consonants, as in *letter* ['lɛ[t]ər]. Schwa is generally represented by the grapheme

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[1] CELEX=CEntre for LEXical information, Nijmegen, The Netherlands

[2] In the phonetic transcriptions, a dot is used to indicate a syllable boundary and square brackets are used to indicate ambisyllabicity.

<e>. Although it is phonetically short, a following intervocalic consonant is not ambisyllabic and there is no double spelling, for example, *beton* /bə.'tɔn/ "concrete." These orthographic regularities may have an effect on the intuitive syllabification of polysyllabic word forms.

EXPERIMENTAL INVESTIGATION OF SYLLABLE STRUCTURE

The experiments reported in this paper investigate how speakers of Dutch affiliate intervocalic consonants after long and short vowels and after schwa. With respect to the short vowel syllables, there are at least three ways to affiliate the single intervocalic consonant of a word form such as *letter*.

First, the consonant could occupy the coda position of the first syllable yielding ['lɛt.ər], as proposed by Hoard (1971) for English. This would be in accordance with the claim that Dutch syllables must have a branching rhyme (see Lahiri & Koreman, 1988; Kager, 1989, 1992), and that therefore open short vowel syllables are not allowed. We will call this the *Branching Rhyme Constraint* (BRC). However, the affiliation of the single intervocalic consonant with the coda position of the first syllable contradicts the *Onset Principle* (OP) according to which onsetless syllables are avoided (Hoard, 1971; Itô, 1989; Kahn, 1976; Selkirk, 1982).

Second, the consonant could be syllable-initial yielding ['lɛ.tər]. According to the OP, intervocalic consonants are affiliated with the onset of the following syllable to avoid vowel-initial syllables. Therefore, a single intervocalic consonant should be syllable-initial because all Dutch consonants are allowed in syllable onset position (Booij, 1995). However, since then the preceding syllable does not have a branching rhyme, the BRC would be violated. For English, Selkirk (1982) suggested a *Basic Syllable Composition* mechanism which syllabifies segments in accordance with a syllable template that respects the OP. In a second step yielding the phonetic surface representation, intervocalic consonants can be resyllabified and become the coda of the preceding syllable. This step is motivated by the fact that single intervocalic plosives are not aspirated — in contrast to plosives in syllable-initial position. According to Selkirk (1982), the ambisyllabic intuition people have about sounds like the [t] in English "butter" is a product of the differing syllable affiliation of the intervocalic consonant at the phonological and the phonetic level.

Third, the consonant could simultaneously be affiliated with the coda of the first syllable and the onset of the second syllable. The single intervocalic consonant would then be ambisyllabic, yielding ['lɛ[t]ər] (Booij, 1995; Gussenhoven, 1986; van der Hulst, 1985; Kahn, 1976). Ambisyllabicity guarantees both that the preceding short vowel syllable is not open and that the following syllable has an onset. Van der Hulst (1985) has pointed out that single intervocalic consonants following short vowels (e.g., *rabbi* ['ra[b]i] "id.") resist final devoicing, which is obligatory in Dutch. Therefore, these consonants cannot be syllable-final. According to the BRC, they cannot be syllable-initial either. Therefore, an ambisyllabic representation seems most appropriate (see Gussenhoven, 1986, for a discussion of ambisyllabicity in British English).

Empirical support for the ambisyllabicity hypothesis in Dutch comes from a study by Zwitserlood, Schriefers, Lahiri, and van Donselaar (1993). The results of their experimental study suggest that words like *letter* ['lɛtər] are syllabified as ['lɛt.tər] by Dutch listeners. In a syllable monitoring experiment, CVC target syllables were recognized significantly faster than CV targets both when the stimulus word had a clear syllable boundary (i.e., CVC.CVC) and when the stimulus had an ambisyllabic consonant (i.e., CV[C]VC). In a control experiment, CVC targets were detected significantly faster in ambisyllabic stimuli than in CVCC control stimuli, and significantly faster than CV targets in ambisyllabic stimuli. These results suggest that the intervocalic consonant formed part of the first syllable in ambisyllabic words.

De Schutter and coworkers (de Schutter & Collier, 1986; de Schutter & Gillis, 1994; Gillis & de Schutter, 1996) investigated syllabification by Dutch speaking children and adults in Belgium. Their participants heard words (e.g., *letter*) which they had to syllabify orally by repeating them in a scanning manner (e.g., *let-ter* or *le-ter*). Gillis and de Schutter (1996) argued that their results do not support the BRC since their participants (adults as well as children) preferred to affiliate an intervocalic consonant following a short vowel with the following syllable, leaving the preceding short vowel syllable unchecked. The proportions of open short vowel syllables varied between 82% for preschoolers and 62% for adults, suggesting that orthographic knowledge influenced syllabification. Thus, it appears that Dutch participants, in cases of conflict, preferred to violate the BRC rather than the OP. It might be the case, however, that participants lengthened the vowel in the first syllable of a word like *kikker* |ˈkɪ[k]ər| "frog" yielding |ˈkɪː.kər|. In that case, the first syllable would be open but still have a branching rhyme. However, according to Gillis (personal communication), this was not the case, although detailed acoustic measurements of the vowel durations have not been carried out. Alternatively, participants may have avoided responses such as *let.ter* because Dutch does not allow for geminate consonants within prosodic words (Booij, 1995). Honoring the universal OP, participants affiliated the intervocalic consonants with the onset of the second syllable leaving the first one open.

To summarize, there are strong linguistic arguments for the claim that open syllables of Dutch may include a long vowel or a schwa, but not a short vowel, and that therefore single intervocalic consonants following short vowels must be ambisyllabic. The results obtained by Zwitserlood et al. are compatible with this view, but those obtained by de Schutter and colleagues are not. The primary goal of the present study was to test whether the main result obtained by de Schutter and colleagues — that intervocalic consonants following short vowels are preferably affiliated only with the onset of the following syllable — could be replicated using a different metalinguistic task. Before turning to the detailed description of the experiments, we will describe the task and discuss how participants may deal with it.

Metalinguistic tasks, such as word games, have become quite popular in psycholinguistic research. Over the last decade, a number of novel word games have been developed (Fallows, 1981; Fowler, Treiman, & Gross, 1993; Treiman, 1983, 1986; Treiman & Danis, 1988; Treiman & Zukowski, 1990, 1996; Treiman, Fowler, Gross, Berch, & Weatherston, 1995). In many of them, participants hear or read input forms which they have to manipulate to yield a particular output form. It is generally assumed that participants learn rules concerning the required manipulation of the input. This view has, however, recently been challenged by Pierrehumbert and Nair (1995), who argue that participants in word game experiments do not internalize rules for manipulating the *input*, but acquire prosodic templates (see McCarthy & Prince, 1993) of the required *output forms*. Accordingly, on each test trial, participants produce the output that best matches the prosodic template.

In their reply to Pierrehumbert and Nair, Treiman and Kessler (1995) point out that the human linguistic processing system does not have to work in terms of template matching even though output templates may be the best way to give an adequate linguistic description of the word game results. Furthermore, they emphasize that participants in word games do not generate output forms from abstract underlying forms, but change one overt word form into another. This makes it unlikely that a process of evaluating several output candidates is involved in performing the task.

In the present study, we used the syllable reversal task introduced by Treiman and colleagues (Treiman & Danis, 1988). In this task, participants hear polysyllabic words and have to produce the second syllable (and any following syllables) first, and then produce the first syllable with a clearly audible break in between. The task is particularly useful for investigating the affiliation of intervocalic consonants because it forces participants to make a decision about the first syllable boundary in polysyllabic words.

This task allows for several different cognitive strategies. First, participants could syllabify phonological input representations. Although current models of spoken word recognition (e.g., SHORTLIST; see McQueen, Norris, & Cutler, 1994; Norris, 1994) do not assume that syllabic units play a role in speech perception, listeners can detect syllable boundaries. Syllable boundaries are often marked by phonetic cues, such as the aspiration of syllable-initial stops in English or the insertion of glottal stops before syllable-initial vowels in German (Lehiste, 1972; Nakatani & Dukes, 1977). Syllabic effects in spoken word recognition suggest that listeners are sensitive to this kind of information (Bradley, Sánchez-Casas, & García-Albea, 1993; Mehler, Dommergues, Frauenfelder, & Segui, 1981; Zwitserlood et al., 1993). The participants in our experiments could create a phonetic or phonological representation of the stimulus, determine the syllable boundary in this representation, read out first the part following, and then the part preceding that boundary.

A related strategy makes use of subvocal repetition of the stimulus. After having recognized the stimulus, participants repeat it subvocally and determine the syllables in this output representation. This could be done in the same way as just described for the phonological input representation. Alternatively, Levelt and Wheeldon (1994; see also Levelt, 1989) have suggested that phonetic encoding for speech production may involve recruitment of syllable units from a *mental syllabary*. Thus, perhaps participants can monitor which syllable units were used in repeating the stimulus and produce them in reversed order.

The third strategy we propose involves orthographic representations. Obviously, in our task a purely orthographic strategy was excluded because the input was auditory and the output a spoken syllable sequence. However, there is evidence that participants use orthographic information even when the experimental task can be solved on the basis of phonological information alone (e.g., Jakimik, Cole, & Rudnicky, 1985; Seidenberg & Tanenhaus, 1979). Accordingly, the participants in our experiments could hear the auditory input, recognize the word, and create the corresponding orthographic representation. Then they could apply orthographic syllabification rules, determine the syllables, and reverse them. The reversed syllables would be phonologically encoded and articulated. Dutch spelling rules prescribe that a hyphen may be placed before a single consonant following a long vowel (e.g., <de-ler>), and between the first and the second of the two consonants following a short vowel (e.g., <let-ter>, <wor-tel>). Thus, the spelling rules transparently reflect vowel length and phonological syllabification.

These strategies all refer to manipulations of the input string. Obviously, participants must process the input string to a certain degree in order to reverse its syllables. However, the initial processing of the input may not fully determine the response, but there may also be certain constraints on the properties of the output. As noted above, Pierrehumbert and Nair (1995) have suggested that participants solve word games on the basis of learned output templates. In our task, the participants probably first reversed the syllables of the input on the basis of certain syllabification rules. But before articulating the reversed syllables, they evaluated the planned utterance by comparing it to a prosodic output template. They could, for instance, apply an output template in which every syllable has an onset and a branching rhyme. Such a template respects the OP and the BRC, and the output would be a well-formed prosodic word. If the planned output does not meet the constraints captured in the template, it may be amended. The planned response [tər-lɛ] may, for instance, be changed to [tər-lɛt] in order to close the short vowel syllable.

Thus, the experimental task could be solved in a number of different ways. The participants must begin by creating some representation of the input, but then they could either syllabify the phonological or the corresponding orthographic representation. In both cases they could evaluate the planned output by comparing it to an output template and alter it if necessary.

The involvement of orthographic strategies will be discussed further below. We assume that in literate adult speakers orthographic and phonological representations are intimately linked and support each other (see also Cowan, Leavitt, Massaro, & Kent, 1982; Cowan, Braine, & Leavitt, 1985). Thus, speakers may know that a word like *deler* has a long vowel because they know how the word sounds and because they know how it is spelled. Though we cannot exclude the possibility that the participants in our experiments sometimes used orthographic knowledge, there are a number of observations that rule out exclusive reliance on that knowledge. For instance, the orthographic rules of Dutch treat double consonants (like <tt> or <kk>) and clusters in exactly the same way, yet the participants of our experiments syllabified words with double consonants and clusters differently. In addition, there were effects of purely phonological variables (most notably stress) that are not reflected in the orthography.

The experiments do not provide any evidence for, or against, the involvement of output templates. Our goal was to obtain behavioral evidence bearing on the claim that syllables with short vowels must be closed and syllables with long vowels or schwa may be left open. Whether effects of vowel type, if they exist at all, arise during the initial partitioning of the input, or are wholly or partly due to the application of output constraints is an issue for further study.

Method

Experiments 1 through 5 used the same task and procedure and were similar in design, the general criteria for the selection of the materials, and the analyses. The experiments only differed in the stimulus materials and the identity of the participants. In the present section we describe those features of the method that are shared by the first five experiments.

Stimuli. The stimuli (except for the pseudo-words in Experiment 3B) were chosen from the

Dutch word form lexicon of the CELEX database. All stimuli were morphologically simple. They were checked by at least five native speakers of Dutch for subjective frequency of use. The materials of all experiments are listed in the Appendix.

The test items were read by a female Dutch native speaker and recorded on DAT. They were further prepared using the computerized signal processing package waves/ESPS running under X-windows on UNIX machines. The items were sampled at 16 kHz and labeled individually using a special labeling program. The acoustic boundaries of each item were determined in the wave form display. Then the master sound file was spliced, yielding one sound file for each experimental stimulus.

The experiments had a within-participant design. Each experiment included items from different stimulus categories. The items were grouped into blocks containing items from each stimulus category. Each participant received all blocks, but the order of the blocks was balanced across participants using a Latin square design. Items within blocks were randomized individually for each participant with the constraint that the first eight items were items with an unambiguous syllabification. After every block there was a short break.

Procedure. Syllabification was investigated with the syllable reversal task used by Treiman and Danis (1988). In this task participants are required to reverse the two parts of a presented bisyllabic word form. If participants hear, for instance, the word *ballon* [bɑ'[l]ɔn] "balloon," they can place the syllable boundary after the intervocalic consonant, producing [ɔn]-[bɑl], or before it, producing [lɔn]-[bɑ], or they can treat the intervocalic consonant as ambisyllabic, producing [lɔn]-[bɑl].

Participants were tested individually. The instructions stated that on each trial they would hear a word, which they should repeat as fast as possible exchanging its two parts. The term *syllable* was not used. The instructions included three examples. If participants had no questions, the experimenter tested whether participants understood the task with two practice items. In the rare event that participants did not respond correctly, they were corrected by the experimenter. Then the experiment started.

Participants sat in front of a computer screen, which was used to indicate the beginning and end of the experiment and the pauses between the experimental blocks. The test items were presented binaurally via headphones. The trial sequencing of the experiment was controlled by means of NESU.[3] On each trial participants first heard a warning signal (a 1 kHz sinusoidal tone of 200 ms) followed by a pause of 200 ms. Then they heard a bisyllabic stimulus word. At the moment of stimulus offset a voice key was activated in order to measure the participants' reaction times (RT). Participants had maximally 2000 ms to respond. 700 ms after speech onset the next trial began. The maximal interstimulus interval was 2700 ms. Participants' responses were recorded on DAT for later analyses.

Classification of the responses and analyses. The experimenter carefully listened to all responses recorded on DAT to classify them. The responses were grouped into three categories: open syllable responses (i.e., responses ending in a vowel), closed syllable responses, and

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[3] NESU (New Experimental Set Up), developed at the Max Planck Institute for Psycholinguistics, constitutes a computerized experimental set-up which includes hardware and software components to design and run experiments.

errors including stuttering, filled pauses (e.g., *ehm*, *ah*, etc.), speech errors (substitutions of segments from outside the stimulus string, blends of syllables, deletions, etc.), and self-corrections. For *letter* [lɛ'[t]ər], [tərlɛ] would be an open syllable response, whereas [tərlɛt] would count as a closed syllable response. The most important dependent variable was the proportion of open syllable responses given to a particular item type. Thus, we computed, for instance, the proportions of open syllable responses to geminate items (number of open syllable responses divided by the total number of responses to geminate items), simple consonant items, and consonant cluster items. To compare these proportions, analyses of variance were carried out with participants and items as random variables (F_1 and F_2, respectively).

Participants. The experiments were carried out with members of the participant pool of the Max Planck Institute for Psycholinguistics. All participants were students of the University of Nijmegen and native speakers of Dutch. They participated in exchange for pay. None of the participants reported any speech or hearing problems. Each person took part in only one of the experiments. There were twelve participants in each experiment except for Experiment 3B (15 participants) and Experiment 5 (22 participants).

EXPERIMENT 1

In Experiment 1, the critical items had a short vowel in the first syllable followed by a single intervocalic consonant. Control items had a long vowel in the first syllable followed by a single intervocalic consonant, or a short vowel followed by a consonant cluster.

Stimuli

144 bisyllabic Dutch nouns which served as stimuli were members of three main categories. The first main category contained words with a short vowel in the first syllable and a single intervocalic consonant. As the intervocalic consonant is represented by a graphemic geminate in the orthography (e.g., *letter*), we called these words *geminate items*. The second main category comprised words with a long vowel in the first syllable followed also by a single intervocalic consonant. The intervocalic consonant is represented by one grapheme (e.g., *deler* ['de.lər] "divisor"), so we called these items *simple consonant items*. The third main category contained words that had a short first vowel syllable and an intervocalic consonant cluster (C-cluster) (e.g., *faktor* ['fɑk.tɔr] "factor"). We called them *consonant cluster items*. The C-clusters were all biphonemic and represented by two graphemes.

In each main category there were four subcategories in order to vary stress (initial vs. final) and length of the second vowel (short vs. long). These variables were crossed. In each subcategory there were twelve items amounting to 48 items in each of the three main stimulus categories.

Some of the vowels in the first syllable of simple consonant items and some of the long vowels in the second syllable were diphthongs or monophthongs that were spelled with two graphemes, for example, *boedel* ['bu.dəl] "possession, property," *koffie* ['kɔ[f]i] "coffee," and so forth. Each subcategory in the categories of geminate and the simple consonant items included at least one member of each of the four main consonant categories, that is

TABLE 1

Results of Experiment 1. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
Geminate	576	77.8	20.8	1.4
Simple consonant	576	10.8	85.4	3.8
Consonant cluster	576	95.7	0.2	4.2

liquids (/l/ or /r/), nasals (/n/ or /m/), fricatives (/s/, /z/, /f/, or /v/), and plosives (/t/, /d/, /p/, /b/, or /k/), in intervocalic position. Due to other constraints on the materials, it was not possible to keep the number of consonants from each class constant across all four subcategories.

Results and Discussion

Analysis of the response types. The proportions of open syllable responses were 20.8% (120 cases) for geminate items, 85.4% (492 cases) for simple consonant items, and only 0.2% (one case) for consonant cluster items (see Table 1). An important result is that all 448 closed syllable responses to geminate items were ambisyllabic responses, that is, a closed syllable response to a word such as *letter* was always *ter-let* and never *er-let*. This result represents strong evidence for the OP and ambisyllabicity.

Analyses of variance were carried out on the proportions of open syllable responses with the crossed variables stimulus category (geminate vs. simple consonant vs. consonant cluster items), stress (initial vs. final), and length of the second vowel (short vs. long). The main effect of stimulus category was significant, F_1 (2, 22) = 182.36, *MSE* = 6.99, $p < .001$, F_2 (2, 132) = 413.39, *MSE* = 3.31, $p < .001$. Newman-Keuls tests revealed that all differences between stimulus categories were significant ($p < .01$) by participants and items.

To test whether participants lengthened or tensed the vowel in the second syllable of open syllable responses to geminate items, thereby "repairing" syllables with final short vowels, we carried out a post-hoc rating test. All open syllable responses to geminate items were spliced from the original recordings of the participants' responses and were re-recorded on a new test tape in random order. Due to technical problems, nine responses were lost. Three phonetically trained raters (two native speakers of Dutch and the first author) listened to the remaining 111 responses and decided in each case whether the final vowel of the response was short (lax) or long (tense). In 79 of the 111 cases two of the three raters judged the vowels in question to be short, and in 56 of these 79 cases the judgements were unanimous. 79 cases correspond to 13.7% of all valid responses to geminate items and 56 cases to 9.7%. Thus, in at least 10% of the cases the participants produced responses ending in short vowels; in at most 10% of the cases they lengthened the final vowel, and in 80% of the cases the second syllable of the response was closed by a consonant. These results clearly contradict the prediction that open syllable responses to geminate items should *never* occur, but they also fail to replicate de Schutter and Collier's (1986) finding that in Dutch open syllable responses are the preferred responses to geminate items.

A closer look at the open syllable responses to the geminate items revealed an effect of stress that was significant by participants but only approached significance by items, F_1 (1, 11) = 16.48, MSE = 0.78, $p < .01$; F_2 (1, 44) = 3.17, MSE = 5.16, $p < .10$. The proportion of open syllable responses was higher for those geminate items that were stressed on the second syllable than for those stressed on the first syllable. It has been claimed in the literature (see Bailey, 1978; Hoard, 1971) that stressed syllables tend to attract (preceding) consonants in order to have an onset. However, this cannot account for the effect of stress found in our experiment since the second syllable always had an onset regardless of whether it was stressed or unstressed. Instead, our data suggest that stressed syllables tend to attract postvocalic consonants to obtain a coda.[4]

The length of the vowel of the second syllable had no significant effect on the syllabification of geminate items. The quality of the intervocalic consonant had an effect on syllabification, which was significant only by participants, $F_1(3, 33) = 3.47$, $MSE = .06$, $p < .05$; $F_2(3, 44) = 0.74$, $MSE = .04$. The proportion of open syllable responses was highest for geminate items with an intervocalic stop (27.1%) followed, in order, by those with nasals (22.6%), liquids (21.2%), and fricatives (15.7%). However, Newman-Keuls tests revealed no significant differences between the four classes of consonants. When liquids and nasals were grouped together (sonorants) and compared to fricatives and stops grouped together (obstruents), there was no significant difference between the proportions of open syllable responses either.[5]

Analysis of the bigram frequencies. Adams (1981) and Seidenberg (1987) have noted that syllable boundaries often fall between two letters that have a low transition frequency compared to the bigram frequencies preceding and following the syllable boundary. That is, the syllable boundary often coincides with a *bigram trough.* To investigate whether participants placed the syllable boundaries in accordance with the bigram trough, the relative bigram

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[4] The analysis of the stress location in the output forms, which was carried out by a native speaker of Dutch, revealed no theoretically interesting results. Except for one participant who stressed the second syllable of the output forms in almost all cases, all participants consistently stressed the initial syllable of the output forms irrespective of whether the input form had initial or final stress. This might be interpreted as the result of a strategy according to which the output forms were produced with the default stress pattern for Dutch.

[5] For analysis of the reaction times (RTs) only those 96.2% of the responses were considered for which the voice key was triggered correctly. The mean RTs were 460 ms for the geminate items (based on 551 cases), 460 ms for the simple consonant items (537 cases), and 409 ms for the consonant cluster items (532 cases). Analyses of variance revealed a significant effect of item category, $F_1(2, 22) = 11.75$, $MSE = 4055$, $p < .001$; $F_2(2, 141) = 5.82$, $MSE = 7738$, $p < .01$. The reaction times support the results from the analysis of the response types in that RTs were fastest for consonant cluster items, the only category which showed an unambiguous response pattern. For the following experiments, no analyses of the RTs are provided because the results for the main categories of items (geminate, simple consonant, and consonant cluster) were very similar for all experiments, and no significant differences were obtained for more subtle distinctions between stimulus categories.

frequencies (per one million word forms) for Dutch were calculated.[6] Then the bigram frequencies surrounding the orthographic (canonical) syllable boundary of the experimental items were looked up: that is, the bigrams <et>, <tt>, and <te> were examined for geminate items such as *letter*, the bigrams <il>, <lt>, and <te> for consonant cluster items such as *filter*, and the bigrams <el> and <le> for simple consonant items such as *deler*. Only those cases are informative in which bigram trough and syllable boundary do not coincide. This was the case for 39.6% of the targets. In 82.3% of the responses to these items, the syllable boundary placed by the participants coincided with the orthographic syllable boundary, and in 10.7% of the responses it coincided with the bigram trough. This shows that the bigram trough is not particularly likely to trigger syllabification. The result supports Treiman and Danis' (1988) and Treiman and Zukowski's (1990) conclusion based on English data that the *bigram trough hypothesis* can generally not account for the results of syllabification experiments.

EXPERIMENT 2

The participants of Experiment 1 showed a strong tendency to close syllables with short vowels, that is, the BRC proved to be very strong. However, because of the transparent representation of vowel length in Dutch orthography, it is unknown whether the participants' syllabification was primarily governed by phonological or by orthographic knowledge. In order to obtain a rough estimate of the strength of orthographic effects, we examined in Experiment 2 the syllabification of those few words of Dutch in which the orthographic representation of vowel length does not follow the general rules.

Stimuli

There were 120 stimuli in this experiment. All items were stressed on the first syllable. There were two main categories of items, each comprising test and control items. The first category, the /x/-items, included seven test items with a short first vowel and the phonologically simple intervocalic consonant /x/. Three items had a long, the others a short, second vowel. The intervocalic consonant is orthographically complex as it is represented by the digraph <ch>, for example, *rochel* ['rɔ[x]əl] "snot." Spelling rules prescribe that both graphemes are part of the second syllable. Thus, phonologically, the intervocalic consonant is ambisyllabic, but orthographically it is affiliated with the second syllable only (<ro-chel>). These items were all Dutch words in this category.

As control items served seven so-called /*f*/-items (e.g., *tegel* ['te.ɣəl] or ['te.xəl] "tile") that also contained a velar fricative in intervocalic position but had a long first vowel. In the controls the velar fricative is represented by the single letter <g>, which belongs orthographically to the second syllable. The voicing opposition between voiceless /x/ (written <ch>) and voiced /ɣ/ (written <g>) specified in CELEX and dictionaries of Dutch is generally not observed in contemporary Dutch (Booij, 1995; Slis & van Heugten, 1989). Most speakers pronounce [+ voice] velar fricatives (spelled <g>) in the same way as [- voice]

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[6] The calculation was carried out by means of an "awk" computer program. It was based on a large newspaper corpus (85 issues of the Dutch newspaper "TROUW" comprising almost five million word tokens).

TABLE 2

Results of Experiment 2. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
/x/	84	57.1	36.9	6.0
/ɣ/	84	4.8	89.3	6.0
English loan words	84	79.8	15.5	4.7
Geminate	84	90.5	2.4	7.1

ones (spelled <ch>). If participants syllabify the items following the orthographic rules, they should produce open syllable responses for test and control items. By contrast, if they honor the BRC, they should produce closed syllable responses for the test items, and open syllable responses for the control items.

The test items of the second category comprised seven English loan words, for example, *tonic* [ˈtɔ[n]ɪk] "id." These items had a single intervocalic consonant spelled as a single letter between two short vowels. Phonologically, the intervocalic consonant is ambisyllabic, but orthographically it is affiliated with the second syllable only. The controls were seven *geminate items*, that is bisyllabic word forms with a single intervocalic consonant which is graphemically represented by a geminate (e.g., *hennep* [ˈhɛ[n]əp] "hemp"). All items had short vowels in both syllables. If participants syllabify as required by the rules of orthography, open syllable responses should predominate for the English loan words and closed syllable responses for the geminate items. By contrast, if the BRC is honored, closed syllable responses should predominate for both item types.

In addition to the 28 test and control items, there were 92 fillers. These items either had a single intervocalic consonant or a consonant cluster.

Results and Discussion

Analysis of the response types. The filler items consisted of word forms in which the syllabification was unambiguous. Responses to the fillers hardly ever deviated from the canonical syllabification and were not further analyzed. With respect to the test items, there were 31 open syllable responses to the /x/-items (36.9%), 75 to the /ɣ/-items (89.3%), 13 to the English loan word items (15.5%), and 2 to the geminate items (2.4%). An overview of all response types for test and control items is given in Table 2.

The differences in the proportions of open syllable responses to English loan words, in which the intervocalic consonant following the short vowel is spelled with one letter, and geminate items, in which the intervocalic consonant is spelled with two letters and the orthographic syllable boundary falls between them, was significant by participants only, $t_1(11) = 2.22$, $MSE = 0.02$, $p < .05$; $t_2(24) = 1.33$, $MSE = 0.04$. This finding constitutes at best weak evidence for the involvement of an orthographic strategy in the syllable reversal task.

The difference between /x/- and /ɣ/-items was significant, $t_1(1, 11) = 7.03$, $MSE = 0.08$, $p < .001$; $t_2(1, 24) = 7.70$, $MSE = 0.04$, $p < .001$. Recall that the first orthographic syllable is open for both item types. Hence, the significant difference between the item types means that syllabification in our task was not *exclusively* governed by orthographic rules. On the other hand, the proportion of open syllable responses to /x/-items (36.9%) was relatively high compared to the geminate items of the present experiment (2.4%) and to the geminate items with initial stress of Experiment 1, where it was 8.0%. This difference may be an orthographic effect. Taken together, the results suggest that the participants relied primarily on phonological information. Orthographic information played at best a minor role.

Analysis of the bigram frequencies. The bigram trough hypothesis was examined by means of the procedure described in Experiment 1. In 22.5% of the items of Experiment 2 the bigram trough and the orthographic syllable boundary were in different locations. The responses for these items coincided with the orthographic syllable boundary in 74.4%, and with the bigram trough in 19.1% of the cases. Thus, again the bigram trough hypothesis cannot account for the response type pattern obtained.

EXPERIMENT 3A

The proportion of open syllable responses to geminate items stressed on the first syllable was much lower in Experiment 2 (2.4%) than in Experiment 1 (8.0%). In Experiment 1, participants gave many open syllable responses to geminate items containing a (short) /ɑ/ or /ɔ/ as the nucleus of the first syllable. Of the 46 open syllable responses to initially stressed geminate items 33 were made when the test item had a (short) /ɑ/ or /ɔ/ in the first syllable. The proportions of open syllable responses were 18.3% for test items with /ɑ/ or /ɔ/ and 8.3% for test items with /ɛ/ or /ɪ/ in the first syllable. A possible explanation for this pattern is based on phonetic facts. The Dutch vowel system differentiates between tense (long) and lax (short) vowels (Booij, 1995). This distinction is not (only) based on differences in duration but also on other phonetic properties (e.g., position of the tongue body). The perception of vowels is mainly based on the first two formant frequencies (F1 and F2). The differences between F1 and F2 are larger within the tense/lax pairs of /i/ and /e/ than within the pairs of /a/ and /o/ (see Koopmans-van Beinum, 1980; Pols, 1977). Thus, the perceptual difference between the members of a tense (long) - lax (short) opposition may be more pronounced in front and high vowels than in back and low vowels. Perhaps this has an articulatory basis, as there is less space for the tongue to mark the contrast between tense and lax vowels by different tongue body positions for the lower than for the higher vowels. This has the acoustic effect that the first two formant frequencies are closer together for tense and lax /a/ and /o/ than for tense and lax /i/ and /e/. Thus, the contrast between the tense and the lax member of a vowel opposition may be less salient for /a/ and /o/ than for /i/ and /e/, such that participants more often perceived a lax (short) /a/ or /o/ of a geminate item as a tense (long) segment than a lax /i/ or /e/, and therefore leave syllables with /ɑ/ or /ɔ/ open more often than syllables with /ɪ/ or /ɛ/. Experiments 3A and 3B investigated systematically whether there is an effect of vowel quality on syllabification.

TABLE 3a

Results of Experiment 3a. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
Geminate	576	89.4	4.7	5.9
Simple consonant	576	4.5	91.0	4.5
Consonant cluster	576	96.2	0.2	3.6

Stimuli

There were 144 items all of which were stressed on the first syllable. The items can be grouped into three different categories. The first category included the test items. These were 48 geminate items which could be further subdivided into four different subcategories, according to the quality of the first vowel, that is, /ɑ/, /ɔ/, /ɪ/, or /ɛ/. In each vowel category there were twelve items such as *bakker* ['bɑ[k]ər] "baker," *fokker* ['fɔ[k]ər] "breeder," *wekker* [ʋɛ[k]ər] "alarm-clock," and *kikker* ['kɪ[k]ər] "frog." The stress location (initial vs. final stress) could not be varied because there were not enough items with final stress. In addition to the test items, there were two categories of filler items with varying vowels. One category comprised 48 simple consonant items which had a long vowel in the first syllable, and the other included 48 consonant cluster items which had a short vowel in the first syllable.

Results and Discussion

There were 27 open syllable responses to geminate items (4.7%), 524 to the simple consonant items (91.0%), and only one to the consonant cluster items (0.2%), see Table 3a.

In one-way analyses of variance on the proportion of open syllable responses the effect of stimulus category (geminate vs. simple consonant vs. consonant cluster) was significant, $F_1(2, 22) = 1026.38$, $MSE = 7.05$, $p < .001$; $F_2(2, 141) = 3171.55$, $MSE = 0.57$, $p < .001$. There were only three more open syllable responses to the /ɑ, ɔ/- geminate items (15 of 576, i.e., 2.6%) than to /ɪ, ɛ/-geminate items (12 of 576, i.e., 2.1%), and in a separate analysis of variance including only responses to geminate items this difference was not significant.

In this experiment, the overall proportion of open syllable responses was lower than in Experiment 1, perhaps because all test items were stressed on the first syllable. In the first experiment there were more open syllable responses for bisyllabic geminate items stressed on the second syllable than for those stressed on the first syllable. Maybe a stronger effect of vowel quality on syllabification can be obtained if the proportion of open syllable responses is increased by using stimuli that are stressed on the second syllable. As a sufficient number of suitable Dutch words could not be found, we designed an additional experiment using bisyllabic pseudowords with final stress.

TABLE 3b

Results of Experiment 3b. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
Geminate	576	38.9	41.3	19.9
Simple consonant	576	14.9	75.0	10.4
Consonant cluster	1152	94.0	1.0	5.0

Although the hypothesized effect of vowel quality on syllabification was not observed, Experiment 3A is important because it replicates the results of Experiment 1 with different materials. Consonant cluster items triggered almost only closed syllable responses, while simple consonant items yielded more than 90% open syllable responses. For the geminate items there were 5% open syllable responses which is comparable to the proportion in Experiment 1 considering items with initial stress only.

EXPERIMENT 3B

Stimuli

There were 192 items which could be grouped into four different categories. All items were bisyllabic pseudowords obeying Dutch phonotactics. Stress was always on the second syllable, for example, *daffel* [dɑ'[f]ɛl]. All items were checked by at least five native speakers of Dutch to make sure that they did not constitute existing Dutch words.

There were 48 test items, 12 in each of the four vowel classes /ɑ/ (e.g., *daffel* [dɑ'[f]ɛl]), /ɔ/ (e.g., *doffel* [dɔ'[f]ɛl]), /ɛ/ (e.g., *deffel* [dɛ'[f]ɛl]), and /ɪ/ (e.g., *diffel* [dɪ'[f]ɛl]). Test items were chosen such that the items in the different vowel classes differed only with respect to the quality of the critical vowel. 48 simple consonant items served as controls. The control items differed from the test items only with respect to the vowel quality in the first syllable, that is they had a tense (long) vowel (as in *daafel* [da.'fɛl], *doofel* [do.'fɛl], *deefel* [de.'fɛl], and *diefel* [di.'fɛl]. Fillers were 96 consonant cluster items, 48 containing a lax (short) vowel in the first syllable, for example, *danfep* [dɑn.'fɛp], *donfep* [dɔn.'fɛp], *denfep* [dɛn.'fɛp], and *dinfep* [dɪn.'fɛp], and 48 otherwise identical items containing a tense (long) vowel in the first syllable, for example, *daanfep* [dan.'fɛp], *doonfep* [don.'fɛp], *deenfep* [den.'fɛp], and *dienfep* [din.'fɛp].

Results and Discussion

There were 297 open syllable responses to the geminate items (41.3%), 540 to the simple consonant items (75.0%), and 15 to the consonant cluster items (1.0%). An overview of all response types in Experiment 3B is given in Table 3b.

Analyses of variance were carried out on the proportions of open syllable responses to geminate items. The independent variable was vowel type (/ɑ/ vs. /ɔ/ vs. /ɛ/ vs. /ɪ/). Its effect was significant by participants and approached significance by items, $F_1(3, 42) = 5.86$, $MSE = 2.76$, $p < .01$; $F_2(3, 44) = 2.52$, $MSE = 8.02$, $p = .07$. There were 170 open syllable responses (23.6%) to /ɑ, ɔ/-geminate items and 127 (17.6%) to /ɛ, ɪ/-items. Planned pairwise comparisons revealed that the mean proportions of open syllable responses differed significantly ($p < .01$) between the /ɑ, ɔ/-items and the /ɛ, ɪ/-items taken together. This is evidence for the hypothesized phonetic (articulatory and acoustic) differences between the tense and lax counterparts of /a/ and /o/ on the one hand and those of /e/ and /i/ on the other hand. Because of these differences, participants were probably more likely to perceive lax /ɑ/ or /ɔ/ than lax /ɛ/ or /ɪ/ as tense; and therefore, they produced more open syllable responses after vowels of the first than of the second group.

In summary, Experiments 1 through 3 showed that there is a strong tendency to close short vowel syllables in Dutch, that is Dutch syllables generally obey the BRC. Furthermore, the experiments showed that there are a number of factors that influence syllabification of words that have an ambiguous syllable boundary. Initially stressed bisyllabic words were shown to trigger closed syllable responses more often than words stressed on the final syllable. The results of Experiment 3B are especially noteworthy because they suggest that the stress value of the first syllable (stressed vs. unstressed) influenced syllabification, and not the complexity or weight of the second syllable. When the first syllable is stressed, the tendency to close short vowel syllables is much stronger than when it is unstressed. However, since the effect in Experiment 3B was found for pseudowords, that is, the factor of stress is confounded with lexicality in this experiment, this particular result should be interpreted with caution. The quality of the intervocalic consonant, and, more importantly, the phonetic quality of the vowel in the first syllable, also affected syllabification. Finally, the results show that orthography plays some role in syllabification in Dutch. Vowel length is generally marked in the orthographic representation, and this has an effect on syllabification.

EXPERIMENT 4

It has been argued time and again that schwa, although phonetically short (Nooteboom, 1972; van Bergem, 1995), occupies two slots on the skeletal tier in Dutch (Booij, 1995). Trommelen (1984) showed that schwa and long vowels have some distributional similarities. Like long vowels, schwa can occur in word-final position (e.g., *akte* [ˈɑk.tə] "folder," *pauze* [ˈpɑʊ.zə] "pause," etc.); short vowels cannot. Neither schwa nor long vowels can precede certain types of C-clusters, for example, nondental clusters and pure sonorant clusters. Furthermore, schwa and the long vowels share the same comparative and diminutive suffixes, while there are different suffixes for the short vowels. These facts led Trommelen to the conclusion that the distribution of schwa in Dutch is highly similar to that of long vowels.

However, there are two features that set schwa apart from the long vowels, as well as from the short ones. First, schwa can never be lexically stressed (van der Hulst, 1984; Kager, 1989; Kager & Zonneveld, 1985–1986; Trommelen, 1984; Zonneveld, 1993). Second, there is evidence from an acoustic study that schwa—contrary to all other vowels—has no articulatory target. Van Bergem (1995) investigated the coarticulatory effects of different consonants and vowels on schwa using $C_1ə'C_2V$- and $'VC_1əC_2$-sequences. He found that the formant frequencies of schwa (in particular F2) were more strongly influenced by the segmental context than those of other vowels. He concluded that schwa has no identity of its own, but is articulatorily determined by the adjacent segments. Articulatory data from American English implies that schwa has an underspecified articulatory target (Browman & Goldstein, 1992).

Although these results suggest that schwa is phonetically different from the long vowels in certain ways, the possibility remains that schwa, like long vowels, occupies two X-slots. If this is the case, bisyllabic word forms containing a schwa in the first syllable and a single intervocalic consonant should be syllabified in the same way as bisyllabic word forms having—ceteris paribus—a long vowel in the first syllable. In contrast, word forms with a short vowel syllable should behave differently with respect to syllabification from both schwa and long vowel words. These predictions were tested in Experiment 4.

Stimuli

Altogether, there were 72 stimuli in the fourth experiment. All items were stressed on the second syllable. It was not possible to vary the stress pattern because schwa can never bear lexical stress (see above).

There were three different categories of test items with twelve items each. The first category, hereafter called /ə/-items, had a schwa in the first syllable and a single intervocalic consonant. The consonant was represented by a single grapheme, for example, *beton* |bə'tɔn| "concrete." The second category of test items had the long vowel /e/ in the first syllable and a single intervocalic consonant, for example *dekaan* |de.'kan| "dean." They were called the /e/-items. The third category comprised the /ɛ/-items, that is word forms with the short vowel /ɛ/ in the first syllable and a single intervocalic consonant, which was spelled with a graphemic geminate, for example, *perron* |pɛ'[r]ɔn| "platform." Because only nine /ɛ/-items could be found, three items in this category had the short vowel /ʉ/ in the first syllable. These three items were not included in the analyses. Additionally, there were 36 filler items consisting of 18 simple consonant items (i.e., having a long vowel in the first syllable) and 18 consonant cluster items (i.e., having a short vowel in the first syllable). Vowels were varied across the filler items.

Results and Discussion

There were 140 open syllable responses to the /ə/-items (97.2%), 141 to the /e/-items (97.9%), 39 to the /ɛ/-items (36.1%), two to the consonant cluster items (0.9%), and 196 to the simple consonant items (90.7%). Thus, as expected, schwa items were treated very similarly to long-/e/-items. Table 4 gives an overview of all response types in Experiment 4.

One-way analyses of variance on the proportion of open syllable responses to /ə/-, /e/-, /ɛ/-items, consonant cluster items and simple consonant items yielded significant effects, F_1 (4, 44) = 240.16, *MSE* = 0.02, $p < .001$; F_2(4, 55) = 157.00, *MSE* = 0.04, $p < .001$. Newman-Keuls range tests were used to make pairwise post-hoc comparisons between the means. The mean proportion of open syllable responses differed significantly between the /ə/-items and both the consonant cluster items and the /ɛ/-items ($p < .01$), but not between the /ə/-items and both the /e/- and the simple consonant (long vowel) items. The difference

TABLE 4

Results of Experiment 4. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
/ə/	144	2.1	97.2	0.7
/e/	144	1.4	97.9	0.7
/ɛ/	144	61.1	36.1	2.8
Consonant cluster	216	95.4	0.9	3.7
Simple consonant	216	6.0	90.7	3.2

between the /e/- and the simple consonant (long vowel) items was not significant either. All other differences were significant. Thus, with respect to syllabification, schwa and long vowels behaved similarly, but differently from short vowels.[7] This result is compatible with the claim that schwa, like the long vowels, occupies two slots on the X-tier, whereas short vowels occupy only one.

EXPERIMENT 5

Experiments 1 through 4 showed that the percentage of open syllable responses to geminate items depended, to some extent, on the stress pattern, the spelling, the type of intervocalic consonant, and the type of vowel in the first syllable. In addition, the proportion of such responses was variable across experiments: The percentage of open syllable responses to geminate items with stress on the first syllable was 8% in Experiment 1, but only 2% in Experiment 2. The materials of these experiments differed in the proportion of stimuli with a long vowel in the first syllable, which invited open syllable responses. The proportion of items with a long vowel was 33% in Experiment 1, but only 22.5% in Experiment 2. The lower percentage of open syllable responses to geminate items in Experiment 2 may be related to the fact that fewer of the other items invited open syllable responses than in Experiment 1. Experiment 5 investigated whether the syllabification of geminate items depended on the composition of the entire item set.

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[7] Materials are transcribed according to CELEX. For some of the /e/-items, however, native speakers of Dutch have different intuitions about the pronunciation of the first syllable vowel. "debuut," "reform," "venijn," and "relikt" are pronounced with a schwa by some speakers. Therefore, additional analyses of variance were carried out grouping the items in question with the /ə/-items. The results did not deviate from the original analysis. The proportion of open syllable responses differed significantly between the stimulus categories ($F_1(4, 44) = 251.84$, $MSE = 0.02$, $p < .001$; $F_2(4, 55) = 161.01$, $MSE = 0.04$, $p < .001$). Newman-Keuls range tests revealed significant differences between the /ə/-items and both the consonant cluster and the /ɛ/-items, but not between the /ə/-, the /e/- and the other simple consonant items.

TABLE 5

Results of Experiment 5. Proportions (%) of closed and open syllable responses and errors for different item categories

			Response syllable type		
Context	*Item category*	*n*	*closed*	*open*	*error*
Simple consonant					
	Geminate	165	87.9	9.7	2.4
	Simple consonant	165	4.2	93.9	1.8
	Consonant cluster	165	96.4	1.8	1.8
Consonant cluster					
	Geminate	165	90.9	2.4	6.7
	Simple Consonant	165	9.1	86.1	4.8
	Consonant cluster	165	97.6	1.2	1.2

Stimuli and Design

In total, there were 165 stimuli in the fifth experiment, all stressed on the first syllable. We had three categories of test items, 15 geminate items, 15 simple consonant items, and 15 consonant cluster items. The test items were balanced with respect to the phonetic quality of the first syllable vowel. Additionally, there were two categories of fillers comprising 60 items each. The first category consisted exclusively of simple consonant items and the second of consonant cluster items.

Half of the participants received the test items together with the first category of fillers, the other half received them with the second category. It was expected that participants would produce more open syllable responses to geminate items in the context of simple consonant fillers than in the context of consonant cluster fillers. The syllabification of the simple consonant and the consonant cluster test items was expected to be stable across context conditions.

Results and Discussion

In the simple consonant context there were 16 open syllable responses to geminate items (9.7%), 155 to simple consonant items (93.9%), and three to consonant cluster items (1.8%). In the consonant cluster context there were four open syllable responses to geminate items (2.4%), 142 to simple consonant items (86.1%), and two to consonant cluster items (1.2%). An overview of all response types per context condition is given in Table 5.

Analyses of variance of the proportions of open syllable responses with context (simple consonant vs. consonant cluster fillers) as between-participants and stimulus category (geminate vs. simple consonant vs. consonant cluster) as within-participants variable revealed a main effect of context, $F_1(2, 40) = 1148.85$, $MSE = 1.07$, $p < .001$; $F_2(1, 42) = 11.46$, $MSE = 0.66$, $p < 0.01$, but no significant interaction of context and stimulus category, $F_1(2, 40) = 1.88$, $MSE = 1.07$; $F_2(2, 42) = 2.25$, $MSE = 0.66$. However, the analyses of simple effects showed a significant effect of context for the geminate items, $F_1(1, 20) = 5.18$, $MSE = 1.26$, $p < .05$; $F_2(1, 42) = 7.32$, $MSE = 0.66$, $p < .05$. For the simple consonant items the effect of context was significant by items and approached significance by participants, $F_1(1, 20) = 4.06$, $MSE = 1.89$, $p = .057$; $F_2(1, 42) = 8.59$, $MSE = 0.66$, $p < 0.01$, while the consonant cluster items showed no effect of context at all.

This result shows that the syllabification of geminate items depended, to some extent, on the experimental context. If the majority of the experimental items was syllabified in a way that left the first syllable open, participants produced more open syllable responses to geminate items—and unexpectedly, to simple consonant items—than if the majority of the experimental items were syllabified with a closed first syllable. The syllabification of consonant cluster items was not affected by the context. This implies that the syllable boundary is clearest for consonant cluster items and somewhat less clear for the simple consonant items. Geminate items show the greatest variability in syllabification. We will return to this finding in the General Discussion section.

EXPERIMENT 6

The percentages of open syllable responses to geminate items in Experiments 1 through 5 were substantially lower than in the studies by Gillis and de Schutter (1996), de Schutter and Collier (1986), and de Schutter and Gillis (1994). This may have several different explanations. First, de Schutter and colleagues carried out their studies with Dutch speaking participants in Belgium. It may be the case that the Dutch spoken in Belgium, that is southern Dutch (SD), differs phonologically from the Dutch spoken in the Netherlands, i.e. northern Dutch (ND). However, according to Gillis (personal communication), there are no phonological or (relevant) phonetic differences between ND and SD that could be invoked to explain the different findings. Alternatively, the difference in the results may be due to subtle methodological differences. For instance, all of our stimuli were spoken by one speaker, who was uninformed about the goals of the experiment, and were later presented from tape. By contrast, in the study by de Schutter and Collier (1986), nine different speakers read out the stimuli directly to the participants. This not only introduces variability within and between experimenters but, more importantly, it is not clear whether the experimenters provided exaggerated clues to syllabification, and where they put the boundaries. Finally, it is possible that the results were different because the required output differed and therefore different output constraints were operative. The low proportion of closed syllable responses in de Schutter and Collier's experiments may be a consequence of the constraint against geminates within prosodic words in Dutch. This constraint may have prevented participants from producing closed syllable responses in the scanning task, but it did not apply in the syllable reversal task.

In short, there are many possible reasons for the differences between our results and those of de Schutter and Collier. The goal of our last experiment was to test whether we could replicate the results of our Experiment 1 with a task more similar to theirs. We used the same materials as in Experiment 1 but asked participants to perform a scanning task similar to de Schutter and Collier's. However, we still presented the stimuli from tape, and we asked the participants to insert a clearly audible pause between the two syllables. This should facilitate the analyses of the responses and, more importantly, rule out the possibility that participants refrain from making closed syllable responses because the output would then include a word-internal geminate.

Method

Stimuli. In the sixth experiment, we used the same stimulus materials as in Experiment 1 (see Appendices A – C). The order of presentation of the stimulus material was also identical to the first experiment.

Procedure. We used a procedure that was similar to the scanning procedure used by de Schutter and colleagues. Participants were tested individually. They heard a bisyllabic stimulus word via head phones. Their task was to repeat the word with a clear audible break between the two parts of the word. The term *syllable* was not used. This task can be considered as a production variant of the "pause-break" task used by Derwing (1992) to investigate the *perception* of syllable boundaries. Participants were asked to pronounce the two parts of the word accurately. The instructions included three examples, one of which was read to the participants by the experimenter. Then the experimenter tested whether participants understood the task with the other two examples. Participants considered the task to be extremely easy to perform. Participants' responses were recorded on DAT for subsequent analyses. The whole experiment lasted less than ten minutes.

Participants. There were twelve participants from the participant pool of the Max Planck Institute for Psycholinguistics who had not taken part in any other experiment reported in this study. All participants were native speakers of Dutch and participated in exchange for pay. None of them reported any speech or hearing problems.

Results and Discussion

The experimenter carefully listened to all the responses recorded on DAT to determine whether participants produced open or closed syllable responses. Responses were generally easy to classify. In the rare event that the pause between the two syllables of a word was too short, the response was counted as an error. There were 112 open syllable responses to geminate items (19.4%), 550 to simple consonant items (95.5%), and two to consonant cluster items (0.3%). An overview of all response types is given in Table 6.

One-way analyses of variance on the proportion of open syllable responses to geminate, simple consonant, and consonant cluster items yielded significant effects, $F_1(2, 22) = 285.44$, $MSE = 6.13$, $p < .001$; $F_2(2, 132) = 966.58$, $MSE = 2.65$, $p < .001$. Newman-Keuls tests revealed that all differences between stimulus categories were significant ($p < .01$) by participants and items.

The results of Experiment 6 are very similar to those of Experiment 1. In both experiments, the proportion of open syllable responses to geminate items was about 20%. As noted above, we do not know why de Schutter and Collier (1986) obtained a much higher proportion of open syllable responses. We have, however, shown that our lower rate is fairly stable across different groups of participants, different materials, and different tasks.

TABLE 6

Results of Experiment 6. Proportions (%) of closed and open syllable responses and errors for different item categories

		Response syllable type		
Item category	*n*	*closed*	*open*	*error*
Geminate	576	79.2	19.4	1.4
Simple consonant	576	4.5	95.5	0
Consonant cluster	576	99.7	0.3	0

GENERAL DISCUSSION

The goal of the present study was to examine how Dutch speakers syllabify bisyllabic words, especially so-called geminate items like *letter*, in which a short vowel is followed by a single intervocalic consonant. On phonological grounds one may predict that the intervocalic consonant should be treated as ambisyllabic, yielding the syllabification *letter* because every Dutch syllable should have an onset and a branching rhyme, and a short vowel alone does not provide for such rhyme. However, in word game studies carried out by de Schutter and colleagues participants preferentially assigned the intervocalic consonant only to the second syllable, leaving the first syllable open. The important implication of their finding is that, contrary to what has often been claimed in the phonological literature, syllables ending in a short vowel appear to be permitted in Dutch.

In order to reassess the syllabification of geminate items, we used the syllable reversal task introduced by Treiman and Danis (1988) instead of the scanning task used by de Schutter and colleagues. In Experiment 1, syllables with a long vowel were usually left open, whereas syllables with a short vowel were usually closed. In many of the cases where such syllables were left open, the vowel was lengthened. Thus, participants showed a strong tendency to produce syllables with a branching rhyme. Nevertheless, there was also a substantial number of responses in which short vowel syllables were left open. Thus, our results neither corroborate the earlier finding that short vowel syllables are preferentially left open, nor do they support the claim that syllables ending in a short vowel do not occur in Dutch.

How likely participants were to produce open short vowel syllables depended, among other things, on the stress pattern of the words. Open syllable responses were more frequent when the short vowel was unstressed than when it was stressed. Thus, it appears that stressed syllables attract coda consonants. At present, we can only observe that this was the case, but we cannot offer an explanation. We cannot argue that a stressed second syllable "takes away" the intervocalic consonant from the first syllable, because *all* second syllables, stressed or unstressed, were provided with an onset.

Experiment 2 was an attempt to examine the strength of orthographic influences on syllabification. This was difficult to do because of the transparent representation of vowel length in Dutch. Our examination of exceptional cases showed that, though orthography may affect syllabification, it is clearly not the only, nor the most important, factor governing it. This is also evident from the effect of stress, which is not represented in the orthography.

The results of Experiments 1 and 2 suggested that open syllable responses might be more likely for syllables including /ɑ/ and /ɔ/ than for syllables including /ɛ/ and /ɪ/, but this hypothesis was not confirmed in Experiment 3A. However, in this experiment the percentage of open syllable responses was generally very low, probably because all words were stressed on the first syllable. In Experiment 3B we tested pseudowords that were stressed on the second syllable and found that a higher proportion of open syllable responses and the expected effect of vowel quality were obtained. Possibly, vowel length was more difficult to determine for /ɑ/ and /ɔ/ than for /ɛ/ and /ɪ/ leading to more open syllable responses for the geminate items of the first group than for those of the second group.

In Experiment 4, we investigated schwa syllables and found them to be treated exactly like long vowel syllables. Thus, a syllable ending in schwa, like a syllable ending in a long vowel, meets the Branching Rhyme Constraint. One way to account for this result is to conclude that Dutch schwa, like long vowels, is associated to two positions on the timing tier. However, as schwa is phonetically short, this may appear rather implausible.

Alternatively, the similar behavior of schwa and long vowels can perhaps be accounted for in terms of Trubetzkoys's *Silbenschnittkorrelation* that distinguishes between *fester Anschluß* (close connection) and *loser Anschluß* (loose connection). When a consonant is closely connected with a preceding vowel, the articulation of the consonant begins before the articulatory movement for the vowel is completed. Trubetzkoy (1939) claimed that the articulation of the vowel is cut short by the consonantal articulation. By contrast, consonants that are loosely connected with the preceding vowel are not initiated before the end of the vocalic articulation. Consequently, the acoustic duration of the vowel is shorter before a closely connected consonant than before a loosely connected one. According to this view, ambisyllabic consonants following short vowels have *fester Anschluß*, whereas intervocalic consonants following long vowels have *loser Anschluß*. Although there is no articulatory evidence for the *Silbenschnittkorrelation* so far (but see Hoole, Mooshammer, & Tillmann, 1994), Trubetzkoy's distinction between *fester* and *loser Anschluß* may be useful to account for the exceptional behavior of Dutch schwa. Although schwa is phonetically short, single intervocalic consonants following schwa are not ambisyllabic. As mentioned above, there are distributional similarities between schwa and the long vowels, but the fact that schwa cannot be lexically stressed distinguishes it from the long vowels. The difference in the syllabification of single intervocalic consonants following short vowels on the one hand and long vowels and schwa on the other hand may therefore be due to a phonetic property possessed only by short vowels but not by long vowels and schwa. Thus, instead of looking for phonological characteristics that long vowels and schwa have in common, we are looking for a feature of short vowels that long vowels and schwa lack. This would be a way to account for the similar distribution of long vowels and schwa without claiming that schwa is phonologically long. Perhaps both long vowels and schwa lack the property of *fester Anschluß*, whereas short vowels have *fester Anschluß*. Under this assumption, the fact that single intervocalic consonants following schwa are syllabified differently from consonants following short vowels becomes plausible.

Dutch has the same phonological constraint as English with respect to short vowel syllables. Therefore, it is interesting to compare our results to those of Treiman and Danis (1988) obtained for English using the same type of word game.[8] The results of the two studies

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[8] It should be noted that Derwing (1992) replicated the main results of Treiman and Danis (1988) using a subset of their materials but applying a perceptual task, that is the "pause-break" task.

are largely compatible. First, and most importantly, we replicate their finding that syllables with a short vowel are usually closed. Second, in both studies there is evidence that syllables with short vowels are more likely to be closed if they are stressed than if they are unstressed.

Treiman and Danis found a robust orthographic effect: The proportion of ambisyllabic responses, that is responses in which the intervocalic consonant was placed in the coda of the original word's first syllable and in the onset of the second syllable, was significantly higher when the intervocalic consonant was spelled with a double consonant (e.g., "comma") than when it was spelled with a single consonant (e.g., "lemon"). For Dutch, the effect of spelling is difficult to test because of the transparency of the Dutch spelling system. Nevertheless we also obtained weak orthographic effects.

Treiman and Danis also investigated the role of the phonetic category of the intervocalic consonant. Participants placed intervocalic nasals or liquids significantly more often in both syllables than intervocalic obstruents. This pattern was not fully replicated in our study. Closed syllable responses were more frequent for geminate items with an intervocalic nasal or liquid than for geminate items with a stop but least likely for those with a fricative. None of these differences was significant. However, our materials were not specifically designed to test the effects of different types of intervocalic consonants.

Taken together, the results of the present experiments suggest that native speakers syllabify words in accordance with the phonological regularities of the language. These regularities appear to be implemented as preferences rather than strict rules. This is evident from the finding that speakers act against the regularities in a significant number of the cases. We observed, for instance, that most participants did not treat all items of a given item category in the same way. Thus, a participant would, for instance, reverse *letter* [ˈlɛ[t]ər] to *ter-let* [tərlɛt] but *kikker* [ˈkɪ[k]ər] to *ker-ki* [kərkɪ]. This is, of course, exactly what one would predict, if the BRC is a preference, but not a strict rule.

In some cases, a number of strong constraints conspire to force a particular syllabification. This is, for instance, why consonant cluster items were virtually always syllabified in the same way. Only the syllabification of *faktor* as *fak-tor* simultaneously satisfies the BRC, the OP, as well as the phonotactic and orthographic constraints of Dutch. In other cases, syllabification is governed by fewer, weaker, or conflicting constraints, and then more variability in the output of the syllabification process is observed.

The results further show that these preferences differ in strength. As we noted above, literally all syllables the participants produced in response to geminate items had an onset. Thus, there was a very strong tendency to honor the OP. The preference for branching rhymes was apparently weaker because syllables with nonbranching rhymes regularly occurred.

We have seen that the BRC is more likely to be honored under some conditions than under others: Violations are particularly frequent when the short vowel is unstressed and when the following consonant orthographically belongs to the next syllable. Thus, we may speculate that there are secondary constraints (e.g., to syllabify according to the spelling rules) supporting the BRC. In Experiment 5 open syllable responses to geminate items were more likely when the fillers were simple consonant items (yielding open syllable responses with a long vowel) than when they were consonant cluster items (yielding closed syllable responses). Two conclusions can be drawn from this finding. First, the observed effect of filler type on the syllabification of the experimental items suggests that there was a minor constraint that a syllable should not only have a branching rhyme but a final consonant. Evidence for such a constraint comes from the observation that when the filler items required closed syllable responses, syllables with a long vowel were also often closed, which is not required by BRC. Second, and more importantly, the effect of filler type shows that the preferences to syllabify words in a particular way are not stable, but context-dependent. If a given constraint has recently, or frequently, been applied, it is likely to be applied again.

We cannot offer a detailed processing model of how stronger and weaker preferences affected the processing of the input and/or the generation of the responses. Perhaps the strength of the preferences corresponds to the order of application. As we pointed out in the Introduction, we cannot determine which preferences are applied during input processing and which during the evaluation of the planned response. But perhaps strong preferences are applied early — during input processing, or as a first monitoring step during the output evaluation — and weak preferences only later, and if time permits.

Obviously, the idea of interacting ranked constraints is strongly reminiscent of current work in Optimality Theory (OT; McCarthy & Prince, 1993). However, we think it would be premature to attempt an OT analysis of the data presented here, as it is not at all clear how to incorporate certain aspects of our findings into current OT. In particular, orthodox OT is "winner-take-all," that is lower-ranking constraints play no role in determining the degree of acceptability of nonoptimal forms. Yet in our data there are clear indications that nonoptimal forms can be nonoptimal to a greater or lesser extent. Reconciling this finding with OT is beyond the scope of the present discussion.

In our view, participants solve the syllable reversal task by applying certain preferences for syllabification to the input, and/or the planned output. An important implication of this view is that the syllabic structure of a word is generated by applying certain routines to the string of segments. Contrary to other proposals in the literature (e.g., Dell, 1986; Levelt, 1989; Shattuck-Hufnagel, 1979, 1983; for a review see Meyer, in press), we maintain that the word form representations in the mental lexicon are not syllabified and that therefore speakers cannot simply look up syllable boundaries in the lexical entries. If they could, it would be difficult to account for the variability of syllabification described above. Supporting evidence for our view that syllabification is generated by rule comes from priming experiments by Roelofs and Meyer (in press; see also Roelofs, 1996) and masked priming experiments by Schiller (submitted).

Finally, one may wonder whether our data have any relevance for theories of speech processing with a wider domain than word games. Obviously our task is not a particularly natural one — although children and adults spontaneously play games of this kind (Bagemihl, 1995; Hombert, 1973, 1986), backward languages such as *Verlan* reverse syllables (Lefkowitz, 1991), and some backward talkers reverse syllables (Cowan et al., 1985). Though the strategies participants used in the syllable reversal task may be developed on the spot, it seems unlikely that they would not build upon their knowledge of their language. Thus, a natural account of the finding that the participants honored the OP in our experiments is that they also honor that priniciple in normal speech production. Similarly, a natural account for the variability of syllabification in the syllable reversal task is that syllabification is also variable in natural speech production. If speakers usually drew on precompiled phonological syllables, it is difficult to see why they would not do this in the present experiments. Thus, we believe that the implications of our findings reach beyond word games. We conclude that syllabification is an on-line process honoring a number of preferences. For Dutch, one strong preference is to provide syllables with an onset, another slightly weaker preference is to create syllables with a branching rhyme, which explains why syllables ending in short vowels are rarely heard.

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[Appendices overleaf:

APPENDICES

Appendix A

Experimental geminate items in Experiment 1

Metrical structure			
Initial stress		*Final stress*	
$[CV[C]_\sigma VC]_\sigma$	$[CV[C]_\sigma VV(C)]_\sigma$	$[CV[C]_\sigma VC(C)]_\sigma$	$[CV[C]_\sigma VVC(C)]_\sigma$
teller	lolly	ballon	malloot
borrel	kerrie	perron	terrein
tunnel	winnaar	sonnet	kommies
rommel	mammoet	collaps	vennoot
visser	koffie	passant	fossiel
cassis	lasso	bassist	dessert
roffel	sessie	terras	passaat
buffel	toffee	buffet	saffier
fakkel	lotto	pakket	rabbijn
letter	mokka	rapport	suppoost
dubbel	rabbi	ballet	kassier
koppel	passie	kokkin	massief

Appendix B

Experimental simple consonant items in Experiment 1

Metrical structure			
Initial stress		*Final stress*	
$[CVV]_\sigma[CVC]_\sigma$	$[CVV]_\sigma[CVV(C)(C)]_\sigma$	$[CVV]_\sigma[CVC(C)]_\sigma$	$[CVV]_\sigma[CVVC]_\sigma$
deler	kilo	mulat	koliek
forum	leraar	barak	huzaar
kamer	kano	roman	komeet
sonar	fauna	monarch	banaan
vezel	sofa	facet	kozijn
tafel	ruzie	vazal	rivier
nevel	visie	racist	bazaar
diesel	kalief	solist	tyfoon
boedel	deemoet	tabak	dekaan
bonus	tapir	delikt	motief
lepel	foto	libel	titaan
beitel	luipaard	raket	kabaal

Appendix C

Experimental consonant cluster items in Experiment 1

Metrical structure			
Initial stress		*Final stress*	
$[CVC]_\sigma[CVC]_\sigma$	$[CVC]_\sigma[CVV(C)]_\sigma$	$[CVC]_\sigma[CVC]_\sigma$	$[CVV]_\sigma[CVVC]_\sigma$
filter	pinda	balkon	diktaat
polder	versie	carbon	kasteel
bunker	tosti	falset	lectuur
tarbot	firma	parket	markies
consul	rosbief	verlof	pastoor
marmer	mensa	marmot	soldaat
balsem	tempo	banket	kultuur
kaktus	wodka	karton	fosfaat
faktor	zombie	verbod	dispuut
kosmos	saldo	kompas	karmijn
mentor	pasta	biljet	ventiel
moslim	porto	servet	sandaal

Appendix D

Experimental test items in Experiment 2

Stimulus category			
/x/-items	/ɣ/-items	English loan words	Geminate items
echo	ego	comic	hennep
jochie	jager	cover	lemmet
lichaam	liga	limit	middel
kachel	kegel	panel	monnik
richel	regel	topic	ridder
bochel	reiger	sheriff	rubber
rochel	beugel	tonic	wekker

[continued

Appendix E

Filler items in Experiment 2

balsem
bangerd
banjo
basis
bengel
binder
bodem
bonsai
boter
bumper
bunker
cantor
circus
column
consul
cursus
deksel
divan
domper
donker
duivel
filter
fistel
hamer
handel
hanger
hemel
hendel
hengel
herder
hertog
hondert
honger
joghurt
jonker
kader
kamfer
kanker
kansel
kapsel
kelder
kinkel
klinker
klungel
koepel
kosmos
koster
laster
lepel
letsel
liter
lomperd
mantel
mentor
meter
moeder
moslim
motor
panter
pater
poker
polder
record
rektor
riedel
rimpel
ruiter
satan
sektor
single
sintel
stencil
stengel
tanker
tempel
tepel
venkel
vinder
vinger
wezel
wimpel
wimper
wingerd
winkel
winter
wonder
wortel
zanger
zender
zuster
zwendel
zwengel

Appendix F

Experimental geminate items in Experiment 3A

Vowel of first syllable			
/ɑ/-items	/ɔ/-items	/ɪ/-items	/ɛ/-items
babbel	bobbel	bikkel	ketter
bakker	fokker	kikker	letter
fakkel	koppel	middel	peddel
gabber	kotter	nikkel	redder
kapper	modder	ribbel	setter
ladder	mokkel	ridder	tekkel
makker	roddel	sikkel	wekker
sabbat	sokkel	wikkel	zetter
waffel	roffel	wissel	keffer
lasser	mossel	sisser	tennis
passer	koffer	dissel	kennel
ballast	roller	giller	teller

Appendix G

Experimental simple consonant items in Experiment 3A

deler
pekel
reuzel
serum
vezel
suiker
kegel
diesel
boedel
titel
lepel
beugel
hemel
meter
riedel
wezel
ruiter
poeder
tepel
virus
divan
sesam
duivel
tumor
visum
vijver
nevel
beitel
regel
zuivel
liter
moeder
reiger
koepel
bezem
bijval
cijfer
bijbel
foetus
humor
ketel
keizer
heuvel
peper
tijger
veter
zegel
buitel

Appendix H

Experimental consonant cluster items in Experiment 3A

filter
consul
faktor
cantor
mantel
kolder
herder
rimpel
handel
cursus
sektor
wimpel
polder
marmer
kosmos
panter
wimper
zender
hertog
zuster
winter
koster
kelder
laster
tarbot
balsem
mentor
domper
hendel
kermis
deksel
letsel
sintel
tempel
wortel
bumper
karper
kaktus
moslim
kansel
vinder
nektar
fistel
rektor
binder
kapsel
kamfer
wonder

[continued

Appendix I

Experimental geminate items (pseudowords with stress on the second syllable) in Experiment 3B

Vowel of first syllable			
/ɑ/-items	/ɔ/-items	/ɪ/-items	/ɛ/-items
daffel	doffel	diffel	deffel
fappel	foppel	fippel	feppel
lammep	lommep	limmep	lemmep
mabber	mobber	mibber	mebber
naffet	noffet	niffet	neffet
naffep	noffep	niffep	neffep
pannel	ponnel	pinnel	pennel
pannep	ponnep	pinnep	pennep
rattek	rottek	rittek	rettek
rattep	rottep	rittep	rettep
saffer	soffer	siffer	seffer
zannek	zonnek	zinnek	zennek

Appendix J

Experimental simple consonant items (pseudowords with stress on the second syllable) in Experiment 3B

Vowel of first syllable			
/a/-items	/o/-items	/i/-items	/e/-items
dafel	dofel	diefel	defel
fapel	fopel	fiepel	fepel
lamep	lomep	liemep	lemep
maber	mober	mieber	meber
nafet	nofet	niefet	nefet
nafep	nofep	niefep	nefep
panel	ponel	pienel	penel
panep	ponep	pienep	penep
ratek	rotek	rietek	retek
ratep	rotep	rietep	retep
safer	sofer	siefer	sefer
zanek	zonek	zienek	zenek

Appendix K

Experimental consonant cluster items (pseudowords with stress on the second syllable) in Experiment 3B

Vowel of first syllables			
/ɑ/-items	/ɔ/-items	/ɪ/-items	/ɛ/-items
barker	borker	birker	berker
danfep	donfep	dinfep	denfep
fampek	fompek	fimpek	fempek
kaftel	koftel	kiftel	keftel
landet	londet	lindet	lendet
landep	londep	lindep	lendep
mabkep	mobkep	mibkep	mebkep
narver	norver	nirver	nerver
narvek	norvek	nirvek	nervek
ramfel	romfel	rimfel	remfel
santek	sontek	sintek	sentek
zarpel	zorpel	zirpel	zerpel

Appendix L

Experimental consonant cluster items (pseudowords with stress on the second syllable) in Experiment 3B

Vowel of the first syllable			
/a/-items	/o/-items	/i/-items	/e/-items
baarker	boorker	bierker	beerker
daanfep	doonfep	dienfep	deenfep
faampek	foompek	fiempek	feempek
kaaftel	kooftel	kieftel	keeftel
laandet	loondet	liendet	leendet
laandep	loondep	liendep	leendep
maabkep	moobkep	miebkep	meebkep
naarver	noorver	nierver	neerver
naarvek	noorvek	niervek	neervek
raamfel	roomfel	riemfel	reemfel
saantek	soontek	sientek	seentek
zaarpel	zoorpel	zierpel	zeerpel

Appendix M

Experimental /ə/-, /e/-, and /ɛ/-items in Experiment 4

	Item category	
/ə/-items	/e/-items	/ɛ/-items
beton	metyl	perron
debat	debuut	terras
gebied	dekaan	dessert
gedicht	decor	pennoen
rebel	detail	vennoot
getal	reform	cellist
tekort	metaal	cheffin
retour	venijn	gekkin
defekt	relikt	terrein
gemak	regime	support[1]
genot	legaat	buffet[1]
belang	delikt	suppoost[1]

[1] first vowel is [ʉ]

Appendix N

Experimental simple consonant and consonant cluster items in Experiment 4

Simple consonant items	***Consonant cluster items***
mulat	balkon
barak	karton
roman	falset
vazal	parket
solist	verlof
tabak	marmot
koliek	diktaat
rivier	markies
huzaar	soldaat
tyfoon	dispuut
kabaal	ventiel
titaan	sandaal
libel	verbod
raket	kompas
loket	servet
komeet	fosfaat
banaan	kultuur
motief	pastoor

Appendix O

Experimental items in Experiment 5

	Item category	
Geminate	*Simple consonant*	*Consonant cluster*
teller	deler	filter
hennep	lepel	vinder
lemmet	hemel	polder
letter	meter	bunker
visser	tepel	zender
ridder	beitel	consul
middel	liter	marmer
borrel	bonus	tempel
roffel	motor	winter
koppel	hekel	balsem
tunnel	forum	kaktus
buffel	tafel	faktor
dubbel	satan	kosmos
fakkel	kamer	sintel
cassis	pater	mentor

Appendix P

Simple consonant filler items in Experiment 5

batik
kano
tapir
beugel
fauna
foto
jager
joker
sofa
kegel
luipaard
leraar
deemoed
honing
liga
kalief
canon
kilo
harem
ruiter

kerel
sater
poker
regel
colon
boedel
koepel
reiger
boter
pekel
serum
ritus
zetel
suiker
kater
cijfer
titel
water
demon
zomer

virus
tumor
kader
sinus
waker
tyfus
telex
foetus
kabel
ratel
humor
ketel
pathos
peper
veter
buidel
beker
datum
retor
woeker

Appendix Q

Consonant cluster filler items in Experiment 5

wortel
nektar
hendel
campus
cirkel
fiskus
gordel
mortel
lektor
perzik
vector
zilver
sultan
vesper
mormel
wimpel
moslim
pinda
versie
kanker
wonder
tostie
tarbot
donker
firma
rosbief
mensa
tempo
kinkel
wodka
zombie
saldo
pasta
cantor
jonker
venkel
porto
circus
herder
kansel
deksel
hertog
rimpel
fistel
zuster
panter
winkel
letsel
rektor
cursus
mantel
binder
koster
domper
laster
kapsel
handel
karper
sektor
kelder