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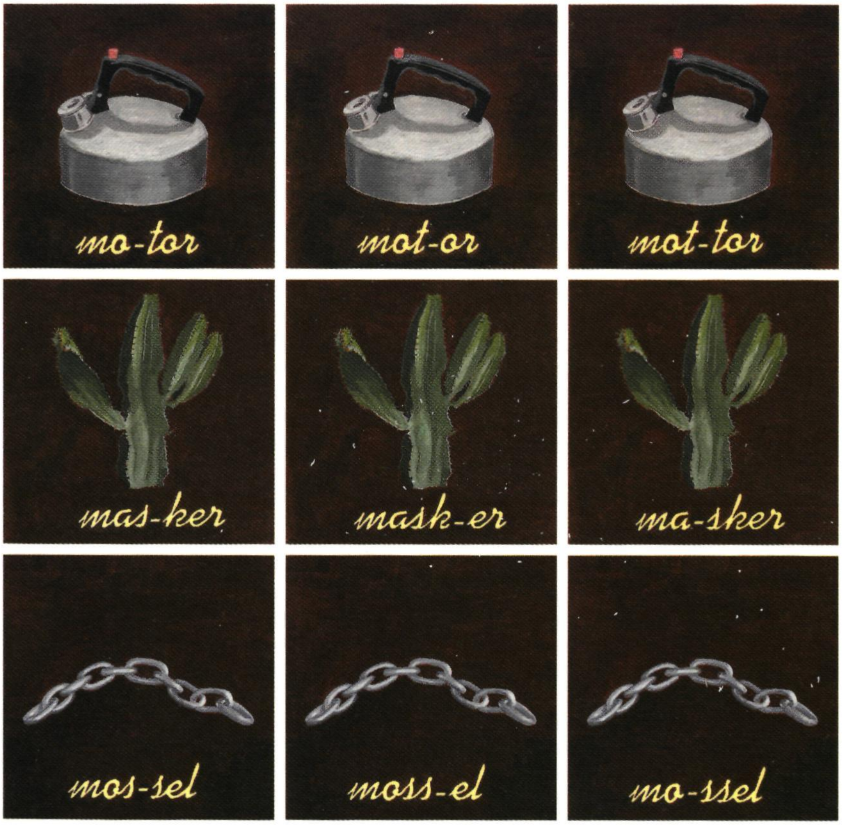
THE ROLE OF THE SYLLABLE IN SPEECH PRODUCTION

Evidence From Lexical Statistics, Metalinguistics, Masked Priming, and Electromagnetic Midsagittal Articulography.

Niels O. Schiller



THE ROLE OF THE SYLLABLE IN SPEECH PRODUCTION

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THE ROLE OF THE SYLLABLE IN SPEECH PRODUCTION

Evidence from Lexical Statistics, Metalinguistics, Masked Priming, and Electromagnetic Midsagittal Articulography

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op het gebied van de Sociale Wetenschappen

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Für meine Eltern

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CONTENTS

INTRODUCTION

CHAPTER 1

A PSYCHOLINGUISTIC MODEL OF SPEECH PRODUCTION

Speaking is a highly complex human skill. Models of speech production try to account for the cognitive processes that occur during speech production. Recently, a number of models have been developed (e.g., Dell, 1986, 1988; Kempen & Hoenkamp, 1987; Levelt, 1989, 1992; Levelt, Roelofs, & Meyer, accepted; Roelofs, 1996; Roelofs & Meyer, in press). These models assume that the speech production process can be divided into three components, i.e., *Conceptualization*, *Formulation*, and *Articulation*. When a speaker has the intention to say something, the Conceptualizer selects the relevant message elements that can inform the listener about what the speaker intends and puts the selected information in the right order taking into account discourse information. The end product of conceptualization is a so-called preverbal message. This preverbal message is generated incrementally, and as soon as parts of the preverbal message are completed, they are fed into the Formulator to make parallel processing during speech production possible. The Formulator translates message into a linguistic structure. This is done via two subcomponents, grammatical encoding and phonological encoding. During grammatical encoding, the concepts intended for expression are lexicalized and syntactic structures are built by means of syntactic building procedures (Bock & Levelt, 1994). The process involved in retrieving lexical items from the mental lexicon is called *Lexicalization*. According to the two-stage model of lexical access (Kempen & Huijbers, 1983; Levelt & Maassen, 1981), first the syntactic properties of a lexical item are selected. This is known as *lemma* selection. Each lexical concept is connected to a lemma which contains the relevant syntactic information, e.g., word class and grammatical gender in the case of nouns. The grammatical encoder uses the lemma information to produce a surface structure consisting of an ordered string of retrieved lexical items. In a second stage called word form retrieval, phonological information for each lemma is accessed.

Evidence supporting the two-stage model of lexical access comes from experimental studies using picture naming and lexical decision tasks (Jescheniak & Levelt, 1994; Levelt, 1992; Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991; Meyer & Schriefers, 1991; Schriefers, Meyer, & Levelt, 1990; for a review see Levelt, Roelofs, & Meyer, accepted). Van Turennout, Hagoort, and Brown (1997) determined the time course of lexical access on-line using event-related brain potentials (ERPs). They provided electrophysiological evidence showing that semantic activation precedes phonological encoding in lexical access.

The phonological encoder generates a sound form for each lemma and for the utterance as a whole (Levelt, 1992). Two kinds of phonological information can be distinguished, i.e., segmental and metrical properties. The segmental information concerns the phonemic structure of a word, whereas the metrical information specifies a lexical item's number of syllables and its lexical stress location, but probably not the syllable-internal structure (Roelofs & Meyer, in press). Segmental and metrical information are supposed to be retrieved separately (Meijer, 1994, 1996; Roelofs & Meyer, in press). During phonological word formation, abstract metrical frames for phonological words are created.

Spelled-out segments are combined with these metrical frames in a process called segment-to-frame association. The model assumes that segments are not marked for syllable position but just for their serial position within a morpheme (Roelofs, 1996). The association of segments to syllable nodes follows universal and language-specific syllabification principles. The domain of syllabification is the phonological word, which can often be larger than the lexical word due to morphophonological processes like inflection or cliticization. As a consequence, syllable boundaries sometimes straddle lexical boundaries as, e.g., in *zij kocht het boek* /zə.kɔx.tət.buk/ ('she bought the book') where the coda /t/ of *kocht* becomes the onset of the following syllable due to the encliticization of the clitic *het* [ət]. Syllabification yields a string of optimally pronounceable syllables for each phonological word.

The output of phonological encoding is a phonological word which is fully specified with respect to its metrical and syllabic structure. It forms the input to the next processing stage, i.e., phonetic encoding. During phonetic encoding the articulatory gestures are specified that are necessary for articulation. Phonetic representations are still abstract in that they do not specify the actual movements to be carried out by the articulatory organs, but rather articulatory tasks in the sense of the task dynamics model (Saltzman, 1986, 1991, 1993; Saltzman & Kelso, 1987; Saltzman & Munhall, 1989). Phonetic representations can be assembled by using the segmental and metrical information specified in the phonological syllables. For high-frequency syllables, however, phonological syllables may also serve as addresses for the retrieval of precompiled articulatory motor programs from a hypothesized mental syllabary (Levelt, 1993; Levelt & Wheeldon, 1994). High-frequency syllables constitute highly overlearned motor patterns. The motor programs are represented by a gestural score, i.e., a phonetic plan that specifies the relevant articulatory gestures and their relative timing. For syllables that are used less frequently the corresponding motor programs are probably not stored in a separate repository but computed on-line.

The end product of phonetic encoding is an abstract phonetic plan, i.e., a program for the articulation of the planned utterance consisting of syllabic gestural scores. This phonetic plan serves as the input to the last processing component, the *Articulator*. The Articulator translates the phonetic plan into motor commands. During motor execution, the motor commands are executed by the coordination of the articulatory subsystems. Articulation can occur under varying circumstances, and motor execution is able to adapt to this within certain limits. The product of articulation is overt speech.

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Syllables play a crucial role at the phonology-phonetics interface in the model. At the phonology-phonetics interface abstract, timeless, and discrete phonological representations, which exist only at a cognitive level, are translated into speech, i.e., a continuous and concrete physical phenomenon that has a certain extension in time and space (see Fowler, 1995 for a review). It is a core assumption of the theory that syllable units are not represented in the form lexicon, but emerge during prosodification. Phonological syllables resulting from segment-to-frame association are abstract units for which a gestural representation, possibly by means of a mental syllabary, must be generated. However, there is relatively little empirical evidence to support this view. This thesis investigates the syllable's role as a processing unit in Dutch speech production.

First, we wanted to know which syllables there are in Dutch and what their distribution in the lexicon is (Chapter 2). Therefore we took the CELEX (CEntre for LEXical information) lexical database for Dutch to compute all occurring syllable structures and their frequencies. There are about 12000 syllable types in Dutch. Our lexico-statistical study revealed that although Dutch has a great variety of syllable structures including very complex onset and coda clusters, there is a core set of relatively simple CV structures (i.e., CVV, CVC, and CVVC) which accounts for more than 70% of all syllables. However, syllables from CELEX result from an isolated word syllabification, and the situation might be different in connected speech. In connected speech phonological sentence-level rules can change the shape of words and their constituent syllables. The word-final /r/ of *filter* ('id.'), for instance, may become the onset of a following syllable due to some encliticization involving, e.g., the conjunction *en* as in *de filter en de koffie* /də.fɪl.tə.rən.də.kɔ[f]i/ ‘the filter and the coffee’. Therefore, the set of syllables occurring in isolated word forms, so-called *lexeme syllables*, may be different from the set of syllables that we encounter in connected speech, so-called *speech syllables*. More importantly, syllable frequencies in connected speech may differ from isolated word form syllable frequencies. To estimate the differences in syllable structure and frequency between isolated word forms and connected speech, we carried out a computational study. The syllables of a contemporary Dutch newspaper corpus were compared before and after the application of phonological sentence-level rules. The overall correlation of syllable frequency between the lexeme and the speech syllables was very high ($r_s = 0.90$). This showed that syllable frequencies based on an isolated word form syllabification represented a reasonable estimate of the syllable frequencies in connected speech. However, on average, the set of speech syllables contained more complex syllable structures than the set of lexeme syllables which is a result of the application of the phonological sentence-level rules. An interesting statistical result for the notion of the mental syllabary was that the vast majority of all syllable tokens in Dutch can be produced with a very small subset of the 500 most frequent syllables. This adds plausibility to the idea of a separate repository of precompiled articulatory motor programs for syllables that are used very often in speech production.

The lexico-statistical study showed that from a theoretical perspective syllables might be useful units in speech production. If high-frequency syllables are stored as whole units in a syllabary, this would greatly reduce the computational load during phonological encoding. However, it is not entirely clear which syllables might be represented in a syllabary. One problem that arose during the lexico-statistical analysis concerned the syllabification of words with ambiguous syllable structure. Dutch syllable rhymes must have a branching structure, e.g., VC, VV, etc. (*Branching Rhyme Constraint*, BRC; see Booij, 1995; Lahiri & Koreman, 1988) and they generally obey the *Onset Principle* (OP; Itô, 1989) which states that syllables should have a consonantal onset. Therefore, the intervocalic consonant of a word like *letter* is assumed to be ambisyllabic, i.e., belonging to the first and the second syllable at the same time, and thus respecting both the BRC and the OP. Using a metalinguistic task we tested whether speakers of Dutch respect these phonological principles in explicit syllabification experiments (Chapter 3). The syllable reversal task developed by Treiman and Danis (1988) was applied to bisyllabic Dutch nouns. Participants received words which belonged to one of the following categories: CVC words such as *filter* /fɪl.tər/ ('id.'), CV words such as *kamer* /ka.mər/ ('room'), and CV[C] words such as *letter* /lɛ[t]ər/ ('id.'). Their task was to produce the two syllables of each word as fast as possible in reversed order, e.g., fil-ter became ter-fil. This task had the advantage of making syllable boundaries explicit and shedding some light on the syllable affiliation of intervocalic consonants. Generally the participants syllabified Dutch nouns in accordance with a small set of prosodic output constraints. Words like *letter* were syllabified as *let-ter* in the majority of the cases, which supports the ambisyllabic interpretation of the intervocalic consonant. Interestingly, however, the first syllable of CV[C] words was left open (e.g., *le-ter*) in a sizeable number of cases showing that participants had different intuitions about the syllabification of certain items. Taken together, the results indicate that syllabification is a variable process which can be influenced by word stress, the phonetic quality of the vowel in the first syllable, and the experimental context. The variability of the results can be accounted for by assuming that the prosodic output constraints differ in their probabilities of being applied.

The results of the syllabification experiments reported in Chapter 3 showed that Dutch speakers can make use of syllables at some level of processing. However, the responses obtained in the syllable reversal experiments were off-line data. To find out more about the time course of syllabification in speech production on-line data are necessary. Baumann (1995) used auditory syllable primes to study the syllabification process in a word production task. However, no matter whether primes were presented shortly before, simultaneously with, or shortly after the presentation of the target stimulus, she never obtained a syllable priming effect in speech production for Dutch. This was, paradoxically perhaps, expected because segments are not specified for their syllable positions in the model. Syllables emerge at a late state during phonological encoding, i.e., during prosodification. However, Ferrand, Segui, and Grainger (1996) using visually masked syllable primes obtained significant syllable priming effects in French. To test whether such an effect could be obtained with Dutch materials, a series of masked syllable priming experiments was conducted (Chapter 4). Participants had to name words or pictures which were preceded by visually masked primes. Targets had CV, CVC, or CV[C] structure. Primes either corresponded to the first syllable of the target or were one segment shorter or longer than the target's first syllable. Neutral primes were included to determine the nature of a possible priming effect. The target *ketel* ('kettle'), for instance, was preceded by the following three primes: `ke###` (syllable match condition), `ket##` (syllable mismatch condition), and `%&$##` (neutral control condition). Irrespective of whether the target was a word or a picture, a syllable priming effect was never obtained. Instead, both CV and CVC primes yielded significant priming effects regardless of the targets' syllable structure. This result supported a *segmental overlap hypothesis*, according to which segmental priming effects increase as the segmental overlap between prime and target increases. The results of this study are in accordance with the model. Since syllables emerge at a late stage during phonological encoding, masked syllable primes preceding the presentation of the targets did not yield a syllable priming effect. The results obtained for French seem to contradict this account. However, perhaps the syllable priming effect in French originates during the *perception* of the prime, and not during the process of speech production itself.

The priming study reported in Chapter 4 as well as Baumann's (1995) study revealed no syllabic effects in phonological encoding for Dutch. However, syllables are conceived of as articulatory motor units in the model. Since syllables are used to specify the gestural commands, which are passed to the *Articulator* to execute the relevant motor actions necessary for overt articulation, it may be possible to find evidence for a syllabic organization of speech on the articulatory output level (Browman & Goldstein, 1988; Byrd, 1995). To test this hypothesis the articulatory timing of intervocalic consonants was investigated (Chapter 5). The articulatory movements of consonants which were segmentally identical but differed with respect to their syllable affiliations were monitored using electromagnetic midsagittal articulography (EMMA) (see Perkell, Cohen, Svirsky, Matthies, Garabieta, & Jackson, 1992; Schönle, 1988; Schönle, Gräbe, Wenig, Höhne, Schrader,

& Conrad, 1987). Participants were instructed to produce multiple repetitions of CV, CVC, and CV[C] words. Items were grouped into triplets such that the first three segments overlapped segmentally (disregarding vowel length), e.g., *fakir* - *faktor* - *fakkel*. However, the crucial intervocalic consonant, i.e., the third segment in each item, had different syllable affiliations. According to the canonical syllabification of the items, /k/ formed the onset of the second syllable in *fakir* ('id.'), the coda of the first syllable in *faktor* ('factor'), and was ambisyllabic in *fakkel* ('torch'). If syllable affiliation is reflected on an articulatory output level, it should be possible to find differences between the three categories of test items with respect to the articulatory timing of the intervocalic consonant, e.g., /k/, relative to an anchor point in the first syllable, e.g., the attainment of the articulatory target for the onset consonant, e.g., /f/. The results of the EMMA study, however, did not support the hypothesis that the stability of the articulatory timing of consonantal gestures varies systematically as a function of syllable affiliation.

Chapter 6 presents the conclusions that can be drawn from the experimental results of the studies reported in Chapters 2 to 5. The impact of the results for the theory of speech production is discussed. The thesis ends with a brief summary of the main results.

REFERENCES

BAUMANN, M. (1995). *The production of syllables in connected speech.* Unpublished dissertation, Nijmegen University.

BOCK, J. K. & LEVELT, W. J. M. (1994). Language production: Grammatical encoding. In M. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 945-984). San Diego: Academic Press.

BOOIJ, G. (1995). *The Phonology of Dutch.* Oxford: Clarendon Press.

BROWMAN, C. P. & GOLDSTEIN, L. (1988). Some notes on syllable structure in articulatory phonology. *Phonetica*, **45**, 140-155.

BYRD, D. (1995). C-centers revisited. *Phonetica*, **52**, 285-306.

DELL, G. S. (1986). A spreading activation theory of retrieval in sentence production. *Psychological Review*, **93**, 283-321.

DELL, G. S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language*, **27**, 124-142.

FERRAND, L., SEGUI, J., & GRAINGER, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, **35**, 708-723.

FOWLER, C. A. (1995). Speech production. In J. L. Miller & P. D. Eimas (Eds.), *Speech, Language, and Communication* (pp. 29-61). San Diego: Academic Press.

ITÔ, J. (1989). A prosodic theory of epenthesis. *Natural Language and Linguistic Theory*, **7**, 217-259.

JESCHENIAK, J. D. & LEVELT, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **20**, 824-843.

KEMPEN, G. & HUIJBERS, P. (1983). The lexicalization process in sentence production and naming: Indirect election of words. *Cognition*, **14**, 185-209.

KEMPEN, G. & HOENKAMP, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science*, **11**, 201-258.

LAHIRI, A. & KOREMAN, J. (1988). Syllable weight and quantity in Dutch. In H. Borer (Ed.), *Proceedings of the 7th West Coast Conference of Formal Linguistics 1988* (pp. 217-228). Stanford, CA: Center for the Study of Language and Information.

LEVELT, W. J. M. (1989). *Speaking. From intention to articulation.* Cambridge, MA: MIT Press.

LEVELT, W. J. M. (1992). Accessing words in speech production: Stages, processes and representations. *Cognition*, **42**, 1-22.

LEVELT, W. J. M. (1993). Timing in speech production with special reference to word form encoding. *Annals of the New York Academy of Sciences*, **682**, 283-295.

LEVELT, W. J. M. & MAASSEN, B. (1981). Lexical search and order of mention in sentence production. In W. Klein & W. J. M. Levelt (Eds.), *Crossing the boundaries in linguistics. Studies presented to Manfred Bierwisch* (pp. 221-252). Dordrecht: Reidel.

LEVELT, W. J. M., SCHRIEFERS, H., VORBERG, D., MEYER, A. S., PECHMANN, T., & HAVINGA, J. (1991). The time course of lexical access in speech production: A study of picture naming. *Psychological Review*, **98**, 122-142.

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

LEVELT, W. J. M., ROELOFS, A., & MEYER, A. S. (accepted). A theory of lexical access in speech production. *Behavioral and Brain Sciences.*

MEIJER, P. J. A. (1994). *Phonological encoding: The role of suprasegmental structures.* Unpublished dissertation, Nijmegen University.

MEIJER, P. J. A. (1996). Suprasegmental structures in phonological encoding: The CV structure. *Journal of Memory and Language*, **35**, 840-853.

MEYER, A. S. & SCHRIEFERS, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **17**, 1146-1160.

PERKELL, J. S., COHEN, M. H., SVIRSKY, M. A., MATTHIES, M. L., GARABIETA, I. & JACKSON, M. T. T. (1992). Electromagnetic midsagittal articulometer systems for transducing speech articulatory movements. *Journal of the Acoustical Society of America*, **92**, 3078-3096.

ROELOFS, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, **35**, 854-876.

ROELOFS, A. & MEYER, A. S. (in press). Metrical structure in planning the production of spoken words. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

SALTZMAN, E. L. (1986). Task dynamic coordination of the speech articulators: A preliminary model. In H. Heuer & C. Fromm (Eds.), *Generation and Modulation of Action Patterns* (pp. 129-144). Berlin: Springer.

SALTZMAN, E. L. (1991). The task dynamic model in speech production. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), *Speech Motor Control and Stuttering* (pp. 37-52). Amsterdam: Excerpta Medica.

SALTZMAN, E. L. (1993). Dynamics and coordinate systems in skilled sensorimotor activity. *Haskins Laboratories Status Report on Speech Research*, **SR-115/116**, 1-15.

SALTZMAN, E. L. & KELSO, J. A. S. (1987). Skilled actions: A task dynamic approach. *Psychological Review*, **94**, 84-106.

SALTZMAN, E. L. & MUNHALL, K. G. (1989). A dynamical approach to gestural patterning in speech production. *Ecological Pychology*, **1**, 333-382.

SCHÖNLE, P. W. (1988). *Elektromagnetische Artikulographie. Ein neues Verfahren zur klinischen Untersuchung der Sprechmotorik* [Electromagnetic articulography. A new method for the clinical investigation of speech motor action]. Berlin: Springer.

SCHÖNLE, P. W., GRABE, K., WENIG, P., HÖHNE, J., SCHRADER, J., & CONRAD, B. (1987). Electromagnetic articulography: Use of alternating magnetic fields for tracking movements of multiple points inside and outside the vocal tract. *Brain and Language*, **31**, 26-35.

SCHRIEFERS, H., MEYER, A. S., & LEVELT, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, **29**, 86-102.

TREIMAN, R. & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

VAN TURENNOUT, M., HAGOORT, P., & BROWN, C. M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **23**, 787-806.

A COMPARISON OF LEXEME AND SPEECH SYLLABLES IN DUTCH

CHAPTER 2

(Slightly adapted version of article published in *Journal of Quantitative Linguistics*, 1996, 3, 8-28)

Niels O. Schiller, Antje S. Meyer, R. Harald Baayen, and Willem J. M. Levelt

ABSTRACT

The CELEX lexical database includes a list of Dutch syllables and their frequencies, based on syllabification of isolated word forms. In connected speech, however, sentence-level phonological rules can modify the syllables and their token frequencies. In order to estimate the changes syllables may undergo in connected speech, an empirical investigation was carried out. A large Dutch text corpus (TROUW) was transcribed, processed by word-level rules, and syllabified. The resulting *lexeme syllables* were evaluated by comparing them to the CELEX lexical database for Dutch. Then additional phonological sentence-level rules were applied to the TROUW corpus, and the frequencies of the resulting connected *speech syllables* were compared with those of the lexeme syllables from TROUW. The overall correlation between lexeme and speech syllables was very high. However, speech syllables generally had more complex CV structures than lexeme syllables. Implications of the results for research involving syllables are discussed. With respect to the notion of a *mental syllabary* (Levelt & Wheeldon, 1994) this study revealed some interesting statistical results. The calculation of the cumulative syllable frequencies showed that 85% of the word tokens in Dutch can be covered by the 500 most frequent syllable types, which makes the idea of a syllabary very attractive.

INTRODUCTION

Syllables play an important role in speech production and perception, as well as in language acquisition. Syllables are the first linguistic units that appear in the course of language acquisition (Liberman, Shankweiler, Fischer, & Carter, 1974). They are earlier accessible than phonemes (Ferguson, 1976; Jusczyk, 1994; Jusczyk, Jusczyk, Kennedy, Schomberg, & Koenig, 1995) and help the child learn prosodic features of the language such as rhythm, i.e., the alternating pattern of strong and weak syllables (Gerken, 1994; Schwartz & Goffman, 1995; Wijnen, Krikhaar, & den Os, 1994). Some researchers (e.g., Berg, 1992; Mehler, Segui, & Frauenfelder, 1981a) have suggested that children first have a phonological representation that is essentially syllabic, and only later acquire a phonemic representation.

In a study by Bertoncini and Mehler (1981) it turned out that 4-week-old infants do much better in discriminating syllable-like stimuli than non-syllable-like stimuli. The authors concluded that infants were able to distinguish between syllables that were allowed in the language under consideration whereas this was not the case with phonologically impossible syllables, although the phonetic manipulations were the same. In fact, there is much evidence available for the syllable being the basic processing unit during speech acquisition.

There are, however, differences with respect to the CV structure of the syllables in the course of language acquisition. Some syllable structures are preferred over others. According to Macken (1995) the acquisition evidence suggests that CV syllables belong to the basic inventory of phonological systems, whereas more complex syllable structures - if allowed by the phonotactic constraints of the language - show up later.

In speech perception, recent research has shown that sublexical units such as the syllable can be crucial in speech segmentation and recognition (Dupoux, 1993; Mehler, Dommergues, Frauenfelder, & Segui, 1981b; Nusbaum & DeGroot 1990; Pitt & Samuel, 1995; see Cutler, 1995 for a review). Using a syllable monitoring task, Mehler et al. (1981b) could show that French subjects were faster in detecting a sequence of phonemes when it corresponded to the first syllable of a stimulus word than when it did not. Cutler, Mehler, Norris, and Segui (1986) could not find such an effect in English (but see also Bradley, Sánchez-Casas, and García-Albea, 1993), but the results in Zwitserlood, Schriefers, Lahiri, and van Donselaar (1993) showed that Dutch listeners were sensitive to the syllabic structure of spoken words (but see also Vroomen & de Gelder, 1994).

In automatic speech recognition systems the syllable has also proved to be a valuable unit (Fujimura, 1975; Mermelstein, 1975; Vaissière 1981). The segmentation algorithm described in Mermelstein (1975), for instance, automatically finds syllable-sized speech units because they are easier to detect than phonetic segments. Later, the syllable-sized units are further divided into individual segments.

Psycholinguistic evidence for the syllable can also be found in the area of speech production. It has often been claimed that segmental speech errors are sensitive to syllable structure, i.e., onsets exchange with other onsets, codas exchange with other codas etc. (MacKay, 1970; Nooteboom, 1969; Shattuck-Hufnagel, 1979; Stemberger, 1982; but see Meyer, 1992 for a review). The syllable also plays an important role in meta-linguistic tasks. Syllable constituents are one of the linguistic units that are preferably manipulated in word games (Hombert, 1986; Laycock, 1972; Lefkowitz, 1991; Bagemihl, 1995 for a review) as well as in backward talking (Cowan, Braine, & Leavitt, 1985; White, 1955).

Under laboratory conditions certain aspects of syllable structure and syllabification have been investigated revealing further evidence for the syllable as a linguistic unit (Fallows, 1981; Fowler, Treiman, & Gross, 1993; Treiman, 1983, 1986; Treiman & Danis, 1988; Treiman & Zukowski, 1990; Wheeldon & Levelt, 1995). Ferrand, Segui, and Grainger (1996) applied (phonological) syllable priming in a word naming task. They obtained reliable facilitation in word naming only when prime and target shared the first syllable compared to the case where they shared a string of phonemes of equal length that did not form a syllable. The authors concluded that the syllable is a functional unit in word naming. In a control experiment using a visual lexical decision task, i.e., a task that could be performed without phonological encoding of the test items, the syllable priming effect disappeared. This supported the claim that the syllable priming effect is located in the output phonology.

Crompton (1981) and later Levelt (1989) assume that there is a library of articulatory routines that is accessed during the process of speech production. Levelt and Wheeldon (1994) further develop this idea into a so-called *mental syllabary*. Syllables are taken to be the basic units of articulatory programming, and syllable-sized articulatory routines are stored in the mental syllabary. The advantage of a mental syllabary is that the computational load of the articulatory programmer during speech production is reduced (Crompton, 1981). Syllables whose articulatory programs (routines) are not stored in the mental syllabary are computed on-line. We will provide some statistical evidence later in this paper that makes the existence of a mental syllabary plausible for the speech production process.

In order to test specific claims about the role of the syllable in a given language, it is necessary to know what the syllable inventory is, and how frequent different syllable types occur. One of the reasons why syllable data are useful is, for instance, that it is possible to find out which syllable types - in terms of the CV structure - predominate in a language. Typological comparisons have shown that there can be large differences in the number of syllable types (Maddieson, 1984) and in the possible CV structures (Blevins, 1995; Greenberg, Osgood, & Jenkins, 1963) between different languages. Although the syllable inventory of a language is dependent on the phoneme inventory, the inventory of suprasegmental contrasts, and the phonotactic restrictions of the language, the relation between these variables is language-specific, i.e., the size of the syllable inventory cannot generally be predicted on the basis of, e.g., the size of the phoneme inventory or the inventory of suprasegmental contrasts. Rather, languages seem to differ in their phonological complexity. In an extensive empirical study, Maddieson (1984) found that the syllable inventory size did not heavily depend on the segment inventory size. In order to test this kind of claims, it is necessary to know what the syllable inventory of a language is and how frequently different syllable types occur.

The frequency of certain syllable types and tokens can be crucial for several reasons. As has already been mentioned above, the syllable seems to be the pivotal unit in first language acquisition. It is known that infants prefer syllables that contain segments with certain places of articulation (see Levelt, 1994 for an overview). However, very little is known about the frequency with which certain syllables occur. To test, for instance, the hypothesis that the child first acquires those syllable types that occur most often in her/his language, the investigator must know which syllables occur in the language and how often they are used.

For theories of spoken word recognition syllable frequencies might also play an important role. Generally, care is taken in word recognition experiments that lexeme frequencies are matched in the different experimental conditions. It might, however, also be important to control for syllable frequencies in that kind of experiments. If high-frequency syllables behave in the same way as high-frequency words - i.e., they are recognized faster than their low-frequency counterparts -, then frequency of syllables could contribute to the word frequency effect in spoken word recognition. In order not to confuse syllable and word frequencies, experimenters have to know the frequencies of the syllables that form part of the word forms.

In speech production there might be articulatory differences between syllables that are high-frequency and the ones that are low-frequency. Syllables that are used more often might show less articulatory variability and a higher degree of intrasyllabic coarticulation than syllables that are less frequently articulated. To test the claim that articulatory routines exist for high-frequency syllables, one needs to know what they are.

This overview suggests that the syllable plays an important role in (psycho-)linguistic research and it appears useful to have an exact description of the syllable inventory of a language. Data on Dutch syllables is available in the CELEX lexical database. These syllable data have two drawbacks, however. Firstly, the syllables are generated on the basis of syllabification of isolated word forms. Secondly, the lexical database for Dutch is completely based on written material, i.e., no speech is included. In connected speech, however, syllabification may deviate from the syllabification of isolated word forms. Due to phonological processes and rules such as the *Onset Principle* (OP) (Hoard, 1971; Kahn, 1976; Selkirk, 1982), which is highly productive in connected speech, syllables without a consonantal onset are unlikely to be produced. In CELEX only those phonological rules that take the prosodic word as their domain had an impact on the resulting syllables. Effects of connected speech such as vowel reduction in unstressed syllables due to articulatory undershoot (Lindblom, 1963), gestural blending and hiding (Browman & Goldstein, 1989), higher level phonological processes (Booij, 1995) such as assimilations, external sandhi (plus subsequent resyllabifications), cliticizations, and other effects that typically can be found in allegro style or informal speech had no influence on words or syllables in CELEX. It is known that there are a number of phonological rules that apply in connected speech and modify the form of the words and - consequently - of their syllables. Therefore, it is desirable to have data about syllables in connected speech.

The present study gives an indirect estimation of what might happen to syllables in connected speech. To investigate this question, a large newspaper corpus was transcribed phonemically, processed by the rules of word phonology, and syllabified by means of a computer program. The output resulted in a set of word-level syllables (hereafter *lexeme syllables*). These lexeme syllables were compared to the CELEX syllable data. Then, an additional set of higher level phonological rules were applied to the same corpus yielding potential syllables of connected speech (hereafter *speech syllables*). The two sets of syllables were compared in terms of their CV structures, their segmental make-up, and their token frequencies. The comparison shows how lexeme and speech syllables differ. Furthermore, information about the frequency of application of phonological rules in Dutch is provided. The implications of this empirical investigation for psycholinguistic research are discussed.

THE SYLLABLE IN DUTCH

Generally, the syllable structure of a language can be defined on the basis of a syllabic CV-template (Itô, 1986, 1989) that specifies the maximal number of Cs in the onset, of Vs in the nucleus, and of Cs in the coda, i.e., the prosodic shape of the maximal syllable. According to Trommelen (1984) and van der Hulst (1984) the syllable template for Dutch can be filled with two Cs in the onset plus an additional C called the *syllabic prefix*, which can only be /s/ (Booij, 1995), two Vs in the nucleus (where V represents a short vowel and VV either a long vowel, a diphthong, or a schwa[1]), and two Cs in the coda plus an additional C in the appendix if a syllable stands in word final position. Exceptionally long codas can have four C positions if they are word-final and follow a short vowel (e.g., 'herfst' /hɛrfst/ ('autumn')). Together, nucleus and coda form the rhyme, which may consist of at most three positions. There are, however, a few exceptionally long rhymes (e.g., 'twaalf' /tʊalf/ ('twelve')) that can have four positions (Booij, 1995).

The syllable template alone does not adequately describe the facts about syllables, however (Selkirk, 1982). In addition to the template, a set of phonotactic constraints (collocational restrictions) is necessary to state which syllables are possible in Dutch. Long vowels, for instance, cannot be followed by a C-cluster consisting of a sonorant plus a non-coronal obstruent (Kager, 1989). It is generally claimed that the co-occurrence restrictions are stronger between nucleus and coda than between the onset and any of the other syllable constituents (Bell & Hooper, 1978; Kuryłowicz, 1948; but see Davis, 1982).

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[1] *Schwa (/ə/), although phonetically short, patterns phonologically with the long vowels in Dutch (Booij, 1995; Kager, 1989; Kager & Zonneveld, 1986; Trommelen, 1984).*

Clements (1990) distinguished a *syllable core* from extrasyllabic elements. According to him, a process of core syllabification which is sensitive to sonority constraints precedes the syllabification of extrasyllabic elements. While core syllables respect the *Sonority Sequencing Generalization* (SSG) (Selkirk, 1984), surface syllables may contain syllabic affixes, i.e., extrasyllabic consonants that often violate the SSG. Extrasyllabic segments therefore have to be described separately (e.g., in the form of auxiliary templates as suggested in Selkirk, 1982). In Dutch, a core syllable can have five X-slots at maximum, i.e., two Cs in the onset and either VCC or VVC in the rhyme. Surface syllables can have additional Cs in onset and coda.

Monomorphemic Dutch words are syllabified in accordance with the OP. There is, however, one problematic case for the syllabification in Dutch. It is generally assumed that a Dutch syllable cannot end in a short vowel (see Booij, 1995; Trommelen, 1984; van der Hulst, 1984; Lahiri & Koreman, 1988; Kager, 1989).[2] That is why a single intervocalic consonant cannot occupy the onset position of the following syllable although this would normally have to be the case according to the OP. Thus, in cases like 'lekker' /lɛkər/ ('tasty'), the /k/ cannot be the coda of the first syllable because this would contradict the OP. But it cannot be the onset of the second syllable, either, because open short vowel syllables are not allowed (for reasons mentioned above). Neither can /k/ be a geminate (i.e., /lɛk.kər/) because geminates are not allowed within a prosodic word (Booij, 1995). One way to account for the (phonological) syllable affiliation of /k/ is to assume that it

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[2] *Kager (1989) summarizes the arguments for this claim. First, short vowels are absent from word final positions. A generalization of this would state that short vowels do not appear in the final position of any syllable. Second, short vowels cannot occupy prevocalic positions, i.e., they cannot occur in hiatus. A third argument comes from stress assignment. In words like 'Armageddon' stress shifts from the (regularly stressed) antepenult to the penult. This, however, presupposes that the penult is a closed syllable that contains a full vowel. This can only be the case if the single intervocalic consonant, i.e., the /d/ closes the syllable. Due to the fact that the OP has a rather strong status in Dutch and that the /d/ does not devoice, which should be the case in syllable-final position, we can assume that the /d/ is more likely to be ambisyllabic than a single coda consonant.*

In spite of these phonological arguments, it has been shown in a recent experimental study by Schiller, Meyer, and Levelt (1997) that native speakers of Dutch to a certain extent do produce open syllables containing short vowels. We suggest that these facts can be accounted for in terms of probabilistically interacting prosodic output constraints. The closing of short vowel syllables is not a categorical rule but rather a highly ranked constraint that can be violated.

is ambisyllabic, i.e., it belongs to both syllables without being represented (or produced) twice (see Ramers, 1988; Vennemann, 1982, 1994 for ambisyllabicity in German). This view is adopted in the present paper.

THE DUTCH SYLLABLE INVENTORY IN CELEX

Phonetic transcription

CELEX is a lexical database that provides syntactic, morphological, phonological, orthographic, and frequency information about Dutch, English, and German word forms. The lemma list for Dutch is based on two different dictionaries[3] and on a large text corpus of the Institute for Dutch Lexicology (INL)[4]. The INL text corpus was also used to determine the word form frequencies in CELEX. According to Burnage (1990) the INL corpus is made up of many different contemporary texts, but spoken language is not included. The phonological form of the entries in the CELEX word form lexicon is represented by a transcription format called Distinct SIngle Character (DISC) that represents each segment by one symbol. The transcription criteria are not strictly phonological. According to the Dutch Linguistic Guide for CELEX, the transcriptions are phonetic for the most part (Burnage, 1990). It seems to be most appropriate to speak of an abstract, prototypical phonetic transcription such as the one given in a dictionary. This seems to be confirmed by the set of phonological rules that were applied in CELEX. Nasal assimilation, for instance, is a phonetically motivated rule that changes an underlying nasal into its phonetic surface realization (e.g., 'aanbieden' ('to offer') /an.bi.dən/ → /am.bi.dən/). The same is true for progressive and regressive voice assimilation, two phonological rules that also yield phonetic surface representations and have been applied in CELEX. All these rules were restricted to word phonology. The general impact of the phonological rules on the Dutch word forms - and hence on the syllables - is described in the next section.

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[3] *Van Sterkenburg, P. G. J. et al. (1984), Van Dale groot woordenboek van hedendaags Nederlands. Utrecht, Antwerpen: Van Dale Lexicografie; Woordenlijst van de Nederlandse taal (1954). 's-Gravenhage: Staatsdrukkerij- en Uitgeverijbedrijf.*

[4] *INL is the abbreviation of Instituut voor Nederlandse Lexicologie.*

Application of phonological rules

In Dutch there are quite a number of word and sentence phonology rules. These rules have different segmental effects on the word forms to which they apply. Three different kinds of rules have to be distinguished with respect to the domain of application: First, there are rules that only apply at the *word form level*, e.g., all kinds of morphophonemic rules and final devoicing. Second, there are rules that can apply both on the word and on the sentence level (for the differentiation between word and sentence level see Booij, 1995). Most often, these rules are obligatory on the word level, whereas they are optional on the sentence level. Among these rules are voice assimilations (regressive and progressive), nasal assimilation, /n/-deletion, degemination (and cluster simplification in general). Third, there are rules that can only apply on the sentence level because their domain of application spans more than one (grammatical) word, e.g., external sandhi, fusions, and cliticizations. In CELEX the first two types of rules have been applied, rules of the second type only on word level. In particular, the rules applied to the word forms in CELEX comprise final devoicing, voice assimilation, nasal assimilation, hiatus rules, and degemination.

The rule of final devoicing applies at a level that is called the word level, e.g., an intermediate level between lexical and postlexical level in the framework of lexical phonology (Booij, 1995; Booij & Rubach, 1987; Kenstowicz, 1994; Kiparsky, 1985; Mohanan, 1986). Final devoicing applies after all morphological rules have applied. It changes all syllable-final voiced obstruents into their voiceless counterparts. Voice assimilation rules are fed by final devoicing, i.e., they apply after all final obstruents have already been devoiced (Slis, 1984; Zonneveld, 1983). Progressive voice assimilation devoices voiced fricatives if they are preceded by another voiceless obstruent. The rule of regressive voice assimilation voices voiceless obstruents followed by a voiced stop. In accordance with the *Elsewhere Principle* (Kiparsky, 1973, 1982) progressive voice assimilation, being more specific, takes precedence over regressive voice assimilation because the former rule is more specific and blocks the application of the latter. Two hiatus rules have the effect of avoiding the clash of two adjacent vowels. Either a consonant is inserted between the two vowels (homorganic glide insertion), or the first of the vowels - if it is a schwa - is deleted (prevocalic schwa deletion). Degemination has the effect of deleting one of two adjacent, identical consonants. A geminate is reduced to a simple consonant. An overview of these phonological rules and their segmental effects is given in Table 1.

Table 1 PHONOLOGICAL WORD-LEVEL RULES IN DUTCH AND THEIR PHONOLOGICAL EFFECTS.

Phonological rule	Example	Phonological effect	
		Underlying form	Surface form
final devoicing	'hond' (dog)	/hɔnd/	[hɔnt]
progressive voice assimilation	'handzaam' (handy)	/hɑndzam/ (/hɑntzam/)[a]	[hɑntsam]
regressive voice assimilation	'handbal' (handball)	/hɑndbɑl/ (/hɑntbɑl/)[a]	[hɑndbɑl]
nasal assimilation	'winkel' (shop)	/wɪnkəl/	[wɪŋkəl]
homorganic glide insertion	'bioscoop' (cinema)	/biɔskop/	[bijɔskop]
prevocalic schwa deletion	'codeer' (coder)	/kodəer/	[koder]
degemination	'ik kan' (I can)	/ik kɑn/	[ikɑn]

[a] *The form in parenthesis reflects the phonological status of the word form after final devoicing has applied.*

In CELEX these phonological rules have been applied to all word forms, i.e., the effect of these rules is represented in the phonetic transcriptions that represent the phonological surface structure of the word forms. These phonetic transcriptions have been syllabified to yield the Dutch syllables.

The syllable data in CELEX are the result of a syllabification algorithm documented in van der Hulst and Lahiri (ms). The rules of syllabification applied in CELEX comprise two parts, core syllabification and stray adjunction. During core syllabification, vowels and consonants are parsed into syllables respecting the constraints of the Dutch core syllable template explained above. Following the OP, as many consonants as allowed by the core syllable template are attached to the left of a syllable nucleus, i.e., to the onset. Word forms are parsed from left to right, i.e., starting with the first syllable of a word. Single intervocalic consonants following short (lax) vowels are made ambisyllabic. Stray consonants, i.e., consonants that could not be attached to a syllable onset, are syllabified in the second step called stray adjunction. During stray adjunction unsyllabified consonants are attached to the syllable onset if they are either word-initial or if they constitute an /s/ followed by a voiceless plosive. Otherwise stray consonants are attached to the coda of the preceding syllable. Syllable frequencies were calculated by summing up all the token frequencies of the word forms in which a particular syllable occurred (Piepenbrock, personal communication).

PREPARATION OF THE CORPUS

The syllabification in CELEX is based on isolated word forms. As we have already mentioned above, the corpus on which the CELEX lexical database for Dutch is based consisted of two dictionaries, i.e., word lists, and a large text corpus, i.e., a running text. However, this running text was parsed into a list of word forms, which then was taken to determine word and syllable frequencies. Hence, although CELEX was partially based on a running text, the syllabification was restricted to isolated word forms.

Thus, it is not clear how well the syllables in CELEX correspond to the syllables in actual connected speech. It is possible, for instance, that a high-frequency syllable in CELEX is actually hardly ever realized because it only appears as a clitic in connected speech (e.g., 'het' /hɛt/), or that a low-frequency syllable in CELEX is high-frequency in connected speech because one or more other syllables change into that syllable due to higher level phonological processes. To investigate the differences between syllables from an isolated word list and from connected speech, a Dutch newspaper corpus of approximately five million word forms was transcribed in phonemic form (DISC notation), processed by a set of phonological rules, and then syllabified by means of the CELEX syllabification algorithm. This corpus comprised 85 issues of the Dutch newspaper 'TROUW' containing 4,863,212 word form tokens in total.[5] The TROUW corpus can be characterized as a contemporary, running text sample of written Dutch. The set of rules comprised the phonological rules that were also applied in CELEX. The resulting set of lexeme syllables from the TROUW corpus was compared to a resampled (lexeme) syllable list of CELEX. In a second step, higher level rules were applied to the TROUW corpus in order to simulate a connected speech condition. The resulting set of potential connected speech syllables was compared to the lexeme syllables from TROUW in order to investigate differences between the two kinds of syllables. The impact of the higher level phonological rules is demonstrated by the frequency of their applications and by the segmental analysis of the speech syllables.

In order to compare the lexeme syllables and the speech syllables, the TROUW corpus had to be transcribed and syllabified. This was done automatically by means of several computer programs described below.[6] The processing of the corpus consisted of three parts, phonemic transcription of the text (grapheme-to-phoneme mapping), application of phonological rules, and syllabification. Care was taken that the latter two steps were carried out in the same way as for CELEX.

Phonemic transcription

The phonemic transcription program can be characterized as a grapheme-to-phoneme mapper for Dutch using the DISC transcription notation. Dutch orthography is relatively transparent as compared to English or German orthography. The general rule that applies in the spelling of Dutch vowels is that long vowels are spelled as single letters in open syllables (including word-final position), and as geminates in closed syllables. There are some problematic cases, however, in particular the grapheme <e>, which can correspond to /e/, /ɛ/, or /ə/.[7] In CELEX accuracy is probably very high

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[5] *All numbers that occurred in the texts were deleted. Also, the attempt was made to delete all proper names and foreign words but not all of them could be detected automatically. The whole remaining text was set to lower case characters.*

[6] *All computer programs used in the empirical investigation reported in this paper were written in the 'awk' programming language and run on UNIX machines.*

[7] *The grapheme <e> represents the long closed vowel /e/. But short open /e/ (/ɛ/) and schwa (/ə/) are also represented by that grapheme. As a consequence, in open syllables <e> can either*

because problematic cases like the transcription of <e> are resolved in a rather secure way: Many words were transcribed by hand.

Application of phonological rules

The second step was to modify the phonemically transcribed words of the TROUW corpus by applying the word-level phonological rules of Dutch. Because there is some degree of abstractness in the Dutch spelling, and in particular the effects of morpholexical rules are always reflected in the orthography (Booij, 1995), morpholexical and allomorphic rules did not have to be applied to the transcribed word forms. By contrast, pure phonological rules of the word level are not necessarily reflected in the spelling. They are obligatory and have to be applied to the transcribed word forms. Care was taken that exactly the same rules were applied as in CELEX as documented in van der Hulst and Lahiri (ms): syllable-final devoicing, progressive and regressive voice assimilation, nasal assimilation, degemination and hiatus rules (homorganic glide insertion, prevocalic schwa deletion).

The phonological rules were implemented in the form of a computer program. They were then applied automatically to the TROUW corpus, i.e., every transcribed word form underwent them. The result of this second step was that all the phonemically transcribed word forms of the TROUW corpus were phonologically modified if they met certain structural conditions. The relative frequency of application of the rules (per one million word forms;

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be /e/ or /ə/ (e.g., /re.dɑk.si/ 'redactie' vs /bə.lop/ 'beloop') and in closed syllables <e> can either be /ɛ/ or /ə/ (e.g., /pɛr.son/ 'persoon' vs /vər.vɔlx/ 'vervolg'). This depends on whether <e> belongs to the root (as in 'redactie') or is part of an affix (as in 'beloop'). As the mapper used hardly any morpholexical information the program could not correctly transcribe all the <e>s. The general rules for the transcription of <e> were the following: In open syllables, <e> was recognized as a long vowel and transcribed as /e/, whereas in closed syllables it was transcribed as /ɛ/. Word-final <e> represents schwa because long /e/ is marked by a vowel geminate, i.e., <ee>, at the end of a word. <ee> was always transcribed as /e/ except for the indefinite article ('een') where <ee> equals a schwa phonologically. The additional transcription rules relate to diminutive forms (<e> → /ə/) and the prefixes 'be-' and 'ge-'. If the strings 'be' and 'ge' were recognized as prefixes, then they were transcribed with schwa. Nevertheless, some <e>s are incorrectly transcribed as /e/ or /ɛ/ (when <e> represented a schwa in fact), whereas the reverse case was unlikely to occur. Thus the frequencies of syllables with either /e/ or /ɛ/ as nuclei are overestimated, whereas schwa syllables are underestimated. Although the grapheme <e> has a high token frequency and the error rate in the transcription of <e> was relatively high, the accuracy of the grapheme to phoneme mapping program reaches more than 98% as could be determined for a sample of 1000 words.

rounded numbers) are given in Table 2.

As can be seen in Table 2, syllable-final devoicing has a high frequency of application compared to the other two voice assimilation rules. The high frequency of application of the degemination rule is due to a characteristic of Dutch spelling. Single intervocalic consonants are geminated after short (lax) vowels. The degemination rule deletes the first C of a geminate to yield the phonemic representation. Therefore, it is important to note that degemination is a spelling-to-sound rule within words, not a phonological rule. Only between words degemination is a phonological rule in Dutch.

Table 2 RELATIVE FREQUENCY OF APPLICATION OF PHONOLOGICAL RULES ON THE WORD LEVEL.

phonological rule	frequency of application (per one million word forms)	segmental effect
syllable-final devoicing	57,030	/b, d/ → /p, t/ /z, v, ɣ/ → /s, f, x/
progressive voice assimilation	5,699	/z, v, ɣ/ → /s, f, x/
regressive voice assimilation	13,971	/s, f, x/ → /z, v, ɣ/ /p, t, k/ → /b, d, g/
nasal assimilation	38,224	/n/ → /ŋ, ɲ, m/
degemination	97,284	/C_1C_1/ → /C_1/ (C_1 = /p, t, k, b, d, s, f, x, z, v, ɣ, m, n, ɲ, ŋ, l, r/)
sum	212,208	

Syllabification

In order to compare syllables from the TROUW corpus and from the CELEX lexical database with each other, the word forms from the TROUW corpus had to be syllabified according to the same syllabification algorithm. One problem for the implementation of the syllabification algorithm in TROUW was the OP. In order to generate correct syllable onsets using onset maximization we had to implement phonotactic constraints on onsets. To do so, we provided the syllabification algorithm with a list of possible syllable onsets in Dutch. This had the drawback that word-internal codas could be drawn into the onset of the following syllable. For instance, in a word form like 'kalfsleer' /kɑlfsler/ ('calfskin'), which consists of the morpheme 'kalf' ('calf'), the linking morpheme 's', and the morpheme 'leer' ('skin'), the syllable boundary falls between the last two morphemes, i.e., /kɑlfs.ler/. But due to the fact that /sl/ is a possible onset in Dutch, our program would syllabify the word as /kɑlf.sler/ following the OP.

The syllabification algorithm was also implemented in a computer program. The computer program was applied to the whole set of phonemically transcribed and phonologically modified word forms. The result was a fully syllabified, phonemically transcribed, and phonologically modified text.

The syllable types of this corpus were listed, and their token frequencies were calculated. Due to idiosyncracies of the corpus (abbreviations, acronyms, non-native word forms, proper names, etc.) 'odd' syllables emerged that were not well-formed and therefore had to be filtered out. For instance, there were 294 syllable types without any nucleus, 11 syllable types with more than one nucleus and 639 syllable types with nuclei that were too long (more than two V-positions). In total, ill-formed syllables amounted to 7.28% of all generated syllable types.

An interesting result was discovered during the statistical analysis of the syllable data in CELEX. The calculation of the cumulative frequency distribution revealed that 85% of all syllable tokens in Dutch can be covered by the 500 most frequent syllables, i.e., less than 5% of the syllable types. This finding is important for the notion of a mental syllabary as it makes the idea of a separate store for high-frequency syllables in terms of their articulatory motor programs very attractive.

Evaluation of the lexeme syllables from TROUW

The TROUW corpus is smaller than the corpus underlying CELEX, and the transcription and syllabification in the present study was less sophisticated than those used in setting up the CELEX data base. Analyses were carried out to determine how closely the two syllable samples corresponded with each other. Only if the TROUW syllable inventory closely resembles the CELEX inventory, and therefore is likely to be a representative sample of Dutch lexeme syllables, the further analyses -- the investigation of the effects of sentence-level phonological rules -- can be of any use.

Table 3 presents a number of summary statistics for our counts of syllables in the CELEX and TROUW corpora. The first three rows of the leftmost column list the number of tokens (N), the number of types (V), and the mean syllable frequency (N/V) in the CELEX lexical database. The third column lists the corresponding statistics for the syllables in the TROUW corpus. The number of syllable tokens in CELEX, approximately 64 million, is much larger than the number of syllable tokens in TROUW, approximately 7 million. This is to be expected, as the CELEX counts are based on a corpus of 42.38 million word forms, while the TROUW corpus contains only 4.86 million words. In spite of this difference in size, the TROUW corpus contains more syllable types (12,000) than CELEX (9,000), so that the mean syllable frequency in CELEX, 6,898.4, is much larger than the mean syllable frequency in TROUW, 610.3.

Does this large difference in mean syllable frequency imply that our syllabification algorithm is unreliable, in that it leads to an overly large number of syllable types for the TROUW corpus? Has the syllabification algorithm produced large numbers of spurious syllable types? To answer these questions, it is necessary to consider in some detail the consequences of the difference in sample size between the CELEX corpus and the TROUW corpus.

It is well known in word frequency statistics that the highly skewed nature of lexical frequency distributions and the large probability mass of unseen types substantially affects sample estimates (see, e.g., Chitashvili & Baayen, 1993; Good, 1953). Figure 1 shows how severely a point estimator such as the arithmetic mean can be affected. To produce this figure, we randomly sampled (without replacement) increasingly large numbers of word tokens (1 million, 5, 10, 15, ..., 40 million) from CELEX. For each sample, we counted the number of different syllables and the mean frequency of these syllables.

Table 3 SUMMARY STATISTICS FOR SYLLABLES IN CELEX AND TROUW.

	CELEX (all)	CELEX (sample)	TROUW (CLX: all)	TROUW (CLX: sample)
N	63,906,898	7,801,701	7,339,860	7,339,860
V	9,264	8,341	12,027	12,027
N/V	6,898.4	935.3	610.3	610.3
median	144.5	26	8	8
N_u	2,588,403	316,453	280,283	288,994
V_u	2,521	1,951	5,284	5,637
N_u/V_u	1,026.7	162.2	53.0	51.3
median$_u$	21	5	2	2
N_uP	4.05%	4.06%	3.82%	3.94%
V_uP	27.21%	23.39%	43.93%	46.87%
N_b	61,318,495	7,485,248	7,059,577	7,050,866
V_b	6,743	6,390	6,743	6,390
N_b/V_b	9,093.7	1,171.4	1,046.9	1,103.4
median$_b$	300	44	31	36
N_uP	95.95%	95.94%	96.18%	96.06%
V_uP	72.79%	76.61%	56.07%	53.13%

N: number of tokens
V: number of types
median: median syllable frequency

N_u: number of tokens unique to corpus
V_u: number of types unique to corpus
median$_u$: median frequency for unique syllables
N_uP: N_u/N

V_uP: V_u/V

N_b: number of tokens in both CELEX and TROUW
V_b: number of types in both CELEX and TROUW
$median_b$: median frequency for shared syllables
N_bP: N_b/N
V_bP: V_b/V

Figure 1 plots the increase in number of syllables (Vs, solid line) and the mean syllable frequency (Ns/Vs, dotted line) as a function of the number of word tokens (Nw) in the sample. As expected, the number of different syllable types increases as the size of the corpus increases. As we continue sampling more words, more and more previously unseen syllables appear, many at first, fewer and fewer as the sample becomes larger.

Interestingly, the mean syllable frequency increases as the corpus size in words is increased. (The increase in mean syllable frequency looks linear to the eye, but the residuals of a linear fit plotted in Figure 2 reveal that a non-linear development is masked by the huge sample sizes involved.)

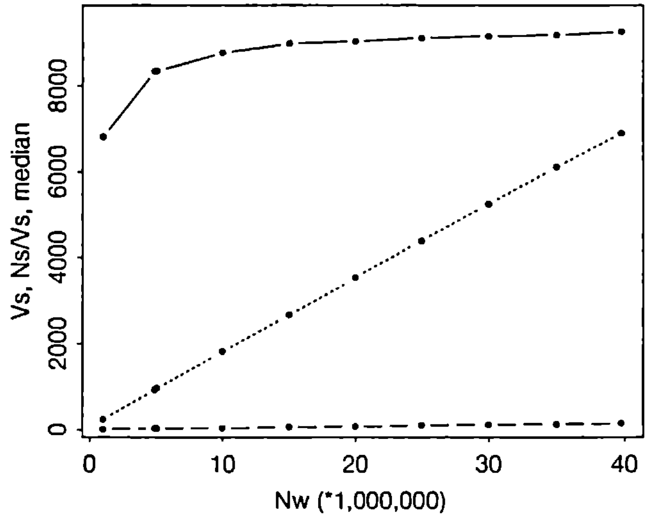

Figure 1 *Plot of the number of syllable types Vs (solid line), mean syllable frequency Ns/Vs (dotted line) and median syllable frequency (dashed line) as a function of corpus size.*

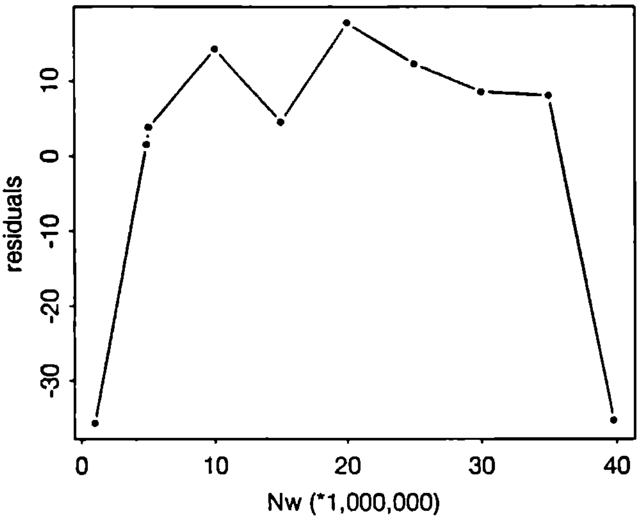

Figure 2 *Plot of the residuals of a linear fit to Ns/Vs.*

A steady increase in the mean as a function of the number of observations does not occur for normally distributed random variables, for which the precision with which the mean is estimated increases with the number of observations, but for which the estimate of the mean itself is more or less constant. But for skewed distributions with high-frequency outliers, the pattern observed for the mean syllable frequency can easily occur.

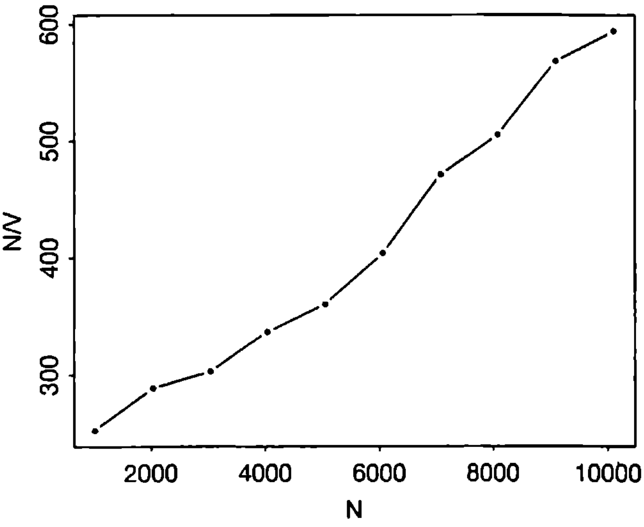

Figure 3 *Plot of the effects of outliers on the mean for a hypothetical example.*

Table 4 presents an artificial example with one high-frequency outlier with a fixed probability of 0.99. The remaining 1% of the tokens represent a number of types that, as is the case for the syllables in CELEX, increases rapidly at first, but increases less rapidly as the sample size increases. The resulting mean increases roughly linearly, as shown in Figure 3.

Table 4 HYPOTHETICAL EXAMPLE OF THE EFFECTS OF OUTLIERS ON THE MEAN FOR DECREASING GROWTH RATE OF THE NUMBER OF TYPES (V).

N (outlier)	N (other)	V	N/V
1000	10	4	252.5
2000	20	7	288.6
3000	30	10	303.0
4000	40	12	336.7
5000	50	14	360.7
6000	60	15	404.0
7000	70	15	471.3
8000	80	16	505.0
9000	90	16	568.1
10000	100	17	594.1

N (outlier): frequency of outlier type
N (other): summed frequencies of non-outliers
V: number of different types
N/V: mean frequency

Given that in our CELEX data some 5% of the types account for roughly 85% of all tokens, i.e., with the 500 most frequent syllable types in CELEX you can construct 84.75% of all syllable tokens, the strong effect of skewness in Figure 1 is easily understood. The dashed line in Figure 1 shows that the median is not affected to the same extent as the mean by the outlier structure.

Nevertheless, the median is not constant, but increases significantly ($r = 0.999$, $p < .0001$) from 10 at 1 million words to 144.5 in the full corpus. This suggests that it is not only the outlier structure, but a more general overall skewness in the frequency distribution that is at issue.

In order to eliminate those differences between the CELEX and TROUW corpora that arise due to a difference in sample size, we selected a random sample (without replacement) of 4,863,212 word tokens (the number of word tokens in the TROUW corpus) from CELEX, and used this CELEX sample to calculate size-adjusted estimates of the number of syllable types and tokens. The results are summarized in the second column of Table 3. The number of syllable tokens in the two samples is now of the same order of magnitude (7.8 million for the CELEX sample, and 7.3 million for the TROUW sample). The mean and median syllable frequencies have also become more similar, but both mean and median are still substantially higher in the CELEX sample than in the TROUW corpus (935.3 and 26 for CELEX, 610.3 and 8 for TROUW). Closer examination of the syllables in the two samples reveals that this difference is largely driven by the syllables that appear in the TROUW corpus only.

The middle section of Table 3 summarizes the frequency distributions of those syllables that are unique to the CELEX and TROUW corpora. Restricting ourselves to the CELEX sample and the TROUW data compared to this sample (the column labeled TROUW CLX: sample), we find that 23.39% of the syllable types in the CELEX sample do not occur in TROUW. These syllables, however, account for only 4% of the syllable tokens in the CELEX sample. In the TROUW corpus, 43.93% of the syllables do not occur in the CELEX sample, but again these types represent only 4% of the tokens in TROUW. This suggests that there is a large number of very low-frequency syllables in TROUW that are the result of incorrect transcription and/or syllabification. Assuming that both the CELEX sample and the TROUW sample would have approximately the same number of unique real syllables, we can estimate the number of spurious syllables in the TROUW corpus by subtracting the number of syllables unique to the CELEX sample (1,951) from the number of syllables (5,637) in the TROUW sample: 5,637 - 1,951 = 3,686. Thus, more than half of the syllable types in TROUW may be suspect. Fortunately, the accuracy of our syllabification algorithm is reasonable token-wise: Only 4% of all tokens in TROUW do not occur in the CELEX sample, for the remaining 96% of the tokens, we may have some confidence that our analyses are reliable.

This conclusion is supported by a comparison of the syllables that appear in both the CELEX sample and the TROUW sample. The third section of Table 3 shows that the mean and median frequencies of the 6,390 syllables common to both samples are quite similar (1,171.4 and 44 for CELEX, 1,103.4 and 36 for TROUW). Inspection of the correlation structure reveals a similar pattern. Figure 4 plots the log (syllable frequency + 1) for the syllables in the CELEX sample and TROUW. The syllables unique to CELEX are represented on the line Y = 0, the syllables unique to TROUW are represented on the line X = 0. Since the scatterplot reveals a heteroskedastic pattern, we have used a non-parametric correlation test (Spearman rank) to ascertain the extent to which the syllable frequencies are correlated. For the join of all syllables in both samples, r_s equals 0.419 ($p < .0001$), for the syllables common to both samples, r_s is 0.821 ($p < .0001$). It is clear that for the higher frequency syllables, the correlations are robust, but that for the lower frequency ranges the correlations become increasingly weaker.

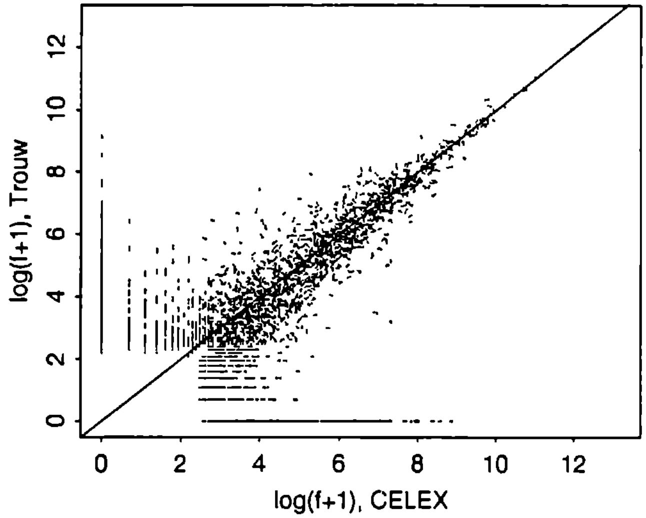

Figure 4 *Scatterplot of log(syllable frequency + 1) for CELEX and TROUW, visualizes the correlation between the syllable frequencies in the two corpora.*

Summing up, our comparison of syllable frequencies according to CELEX and TROUW shows that our simple syllabification algorithm is reasonably reliable for token-based analysis with an error rate of less than 5%, but that for type-based analysis a substantial number of possibly spurious syllables has been generated.

SPEECH SYLLABLES IN TROUW

Application of sentence-level rules

As already mentioned, for some research questions it might be interesting to know whether the lexeme syllables of a language give a good estimation of those syllables that appear at a phonetic surface level in connected speech, i.e., of the speech syllables. If word forms are uttered in a linguistic context, many phonological rules of connected speech apply (above the isolated word level) which can alter the phonetic form of a word, and of its syllables. To test whether the lexeme syllables and their token frequencies give a good estimation of the syllables and their corresponding token frequencies in connected speech, the potential connected speech syllables were generated from TROUW. The reason why we could not generate speech syllables from CELEX but had to use a new corpus was that the INL text corpus, on which the Dutch lexical database of CELEX is based, is not directly accessible via CELEX.

To obtain the *speech syllables*, the following set of connected speech sentence-level rules were applied to the transcribed and syllabified TROUW corpus: progressive and regressive voice assimilation, nasal assimilation, C-cluster simplification (including degemination), /n/-deletion, external sandhi, and different fusions and cliticizations. Some of these rules had already been applied on the word level. On the sentence level they can apply again if the necessary structural conditions are met between word boundaries. Other rules can only apply on a higher level, e.g., external sandhi (Nespor & Vogel, 1982; Stroop, 1986; Vogel, 1986), fusions, and cliticizations (Berendsen, 1986; Booij, 1995). They often have the effect of shifting syllable boundaries. Such *resyllabification* occurs whenever a word form ending in a consonant is followed by a word form beginning with a vowel. In accordance with the OP the coda consonant is shifted to the onset of the following syllable yielding a resyllabification (e.g., '[ik] denk over' /dɛŋk.o.vər/ → /dɛŋ.ko.vər/. In Dutch, resyllabification blocks /n/-deletion, e.g., 'vragen over' becomes /vra.ɣə.no.vər/ because /n/ only deletes in coda position. Cliticization attaches function words to their host words if the former occur in their weak forms called clitics (Booij, 1995). Clitics can either pro- or encliticize, but in Dutch enclisis is preferred. Schwa-initial clitics induce resyllabification if they attach to a preceding word with a final consonant. The clitic usually wins an onset, e.g., 'ik denk het' /ɪk.dɛŋk.hɛt/ → /ək.dɛŋ.kət/ (or even /kdɛŋ.kət/). If several function words occur in sequence, contraction (fusion) can occur, i.e., cliticization plus partial deletion, e.g., 'dat ik' /dɑt.ɪk/ → /dɑk/. These are phonological rules of connected speech above the word level in Dutch that have the most impact in sentence phonology (for additional rules see Booij, 1995, Chapter 7).

Application of these phonological rules led to the set of speech syllables. In general, the rules apply depending on speech rate, style, and stress conditions, etc. In the present empirical investigation the effects of these rules were maximized. To achieve this, the connected speech level phonological rules were applied whenever it was possible (*worst case scenario*), i.e., whenever a phonological string was a possible input for these rules.

The phonological rules of the sentence level were implemented and were added to the existing computer programs used for the generation of the lexeme syllables. Then the modified programs were applied to the TROUW corpus again.

From the resulting 17,642 speech syllables types 1,124 syllables were removed because they were ill-formed.[8] These were 367 syllable types without any nucleus, 57 syllable types with more than one nucleus and 700 syllable types with nuclei that were too long (i.e., three vowel phonemes) yielding 6.37% of all 17,642 syllable types generated. The cleaned list of speech syllables comprised 16,518 types which had a mean token frequency of 91.09 (per one million word forms) (SD = 982.30). In order to compare the 12,027 lexeme syllables from TROUW with the 16,518 speech syllables from TROUW, both lists were matched and the subset of syllable types represented

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[8] *The reason why ill-formed syllables occurred at all was that the newspaper corpus contained all kinds of texts, e.g., crossword puzzles, chess puzzles, stock reports, sport reports, etc. Ill-formed syllables were likely to arise when character strings contained in these "texts" were syllabified. Another source of ill-formedness were abbreviations, acronyms (some of which occur very frequently in Dutch, e.g., 'a.u.b.', 'blz', 'hfl', etc.), (foreign) proper names, loanwords, etc. Due to the fact that the trancription component had neither a morphological parser nor a lexicon in which word forms could be looked up in order to decide whether a particular word form was a proper word, a non-word, an abbreviation, or a proper name, the ill-formed syllables had to be filtered out at this point in the processing.*

in both lists was determined.

Table 5 RELATIVE FREQUENCY OF APPLICATION OF PHONOLOGICAL RULES ON THE SENTENCE LEVEL.

phonological rule	frequency of application (per one million word forms)	segmental effect
progressive voice assimilation	37,188	/z, v, ɣ/ → /s, f, x/
regressive voice assimilation	42,691	/s, f, x/ → /z, v, ɣ/ /p, t, k/ → /b, d, g/
nasal assimilation	11,683	/n/ → /ɲ, ŋ, m/
C-cluster simplification (including degemination)	4,428	$/C_1C_1/ \rightarrow /C_1/$ (C_1 = /p, t, k, b, d, s, f, x, z, v, ɣ, m, n, ɲ, ŋ, l, r/)
/n/-deletion	95,455	/n/ → /∅/
external sandhi	160,864	shift syllable boundary
fusions (total)	1,595	fuse pronouns with auxiliaries
cliticizations (total)	21,293	cliticize pronouns to hosts
sum	375,196	

Comparison of lexeme and speech syllables

Table 5 shows how often (per one million words) each higher level phonological rule was applied to the TROUW corpus. The high frequency of application of assimilation rules is striking. These rules applied whenever a voiceless obstruent was followed by a voiced fricative (progressive voice assimilation), a voiceless obstruent by a voiced stop (regressive voice assimilation), or a nasal by a non-coronal stop (nasal assimilation). Those contexts occurred with high frequency in the corpus. The high number of /n/-deletions is due to the fact that application of this rule on the word level was blocked in order to give resyllabification the possibility to apply. By far the most frequently applied rule is external sandhi resulting in resyllabification. In total, sentence-level phonological rules were applied more than 375,000 times per one million words. Thus, on average, every third word was affected by application of a sentence-level rule. To our knowledge, the present study is the first one to provide an estimate of the frequency of application of sentence-level rules.

Given the high rate of rule application, strong effects on the syllable inventory may be expected. We compared the size of the lexeme and speech inventories and the distribution of different syllable types in each of them. There were many more syllable types in the speech than in the lexeme syllable inventory. 11,050 syllable types appeared in both corpora, 977 only in the lexeme but not in the speech corpus, and 5,468 only in the speech, but not in the lexeme corpus.

Figure 5 illustrates the distribution of the lexeme and speech syllables in terms of rank-frequency curves. In fact, both curves cross each other, i.e., the high-frequency lexeme syllables have a higher frequency than the high-frequency speech syllables, whereas with respect to the low-frequency syllables the speech syllables have a higher frequency than the low-frequency lexeme syllables. The speech syllable inventory was more diverse in terms of syllable types than the lexeme syllable inventory. Figure 5 shows that this higher diversity is for the most part a result of additional low-frequency syllable types (cf. the difference in the number of rank positions between both curves). The high number of new types among the speech syllables is mainly due to the fact that the sentence-level rules generated syllables that were not allowed on the word level. 2,812 (51.43%) of the "newcomers" ended in voiced obstruents. These syllables were created by application of regressive voice assimilation. Due to the application of final devoicing, the lexeme syllable inventory did not include any syllables with final voiced obstruents. 298 (5.45%) of the newcomers included consonant clusters that were not permitted at the word level. As discussed above, we assumed, following Laeufer (1995) and Booij (1995), that collocational constraints are relaxed in fast speech and that the general sonority-based constraints determine syllabification. Therefore, syllables such as /kfru/ and /ksli/ were created.

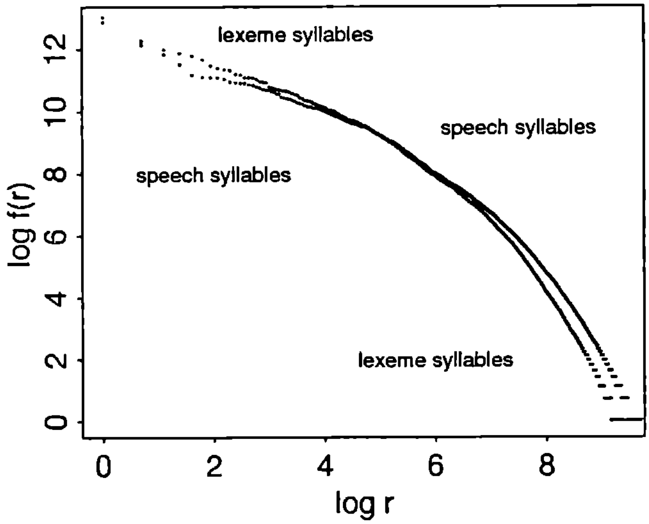

Figure 5 *Plot of the distribution of lexeme and speech syllables in terms of rank-frequency curves.*

Table 6a gives an overview of the relative frequencies of the most common CV structures in the lexeme and speech syllable type inventories. The most frequent CV structures were the same in the three inventories, but their ranking differed. On the whole, the most frequent TROUW speech syllable types were more complex in terms of CV structure than the lexeme syllable types.

Next, the token frequencies of the syllables in the two inventories were compared. Overall, the correlation of syllable frequencies between the two inventories was high: $r_s = 0.90^{**}$ when calculated only across those syllables included in both inventories (intersect), and $r_s = 0.62^{**}$ when all syllables were included and the frequency of the syllables that were only represented in one of the inventories was set to zero in the other inventory (join). Thus, generally speaking, the lexeme frequencies represented a reasonable estimate of the frequencies in the speech syllable inventory.

Table 6a CV STRUCTURES AND CORRESPONDING PROPORTION OF ALL SYLLABLE TYPES.

CELEX lexeme syllables		TROUW lexeme syllables		TROUW speech syllables	
CV structure	**% of all syllable types**	**CV structure**	**% of all syllable types**	**CV structure**	**% of all syllable types**
CVVC	16.37	CVCC	15.62	CVCC	13.33
CVC	13.03	CVVC	12.17	CCVC	11.44
CVCC	12.66	CVC	10.91	CCVVC	11.29
CVVCC	10.35	CCVC	10.28	CVVC	10.98
CCVVC	9.52	CCVVC	9.26	CCVCC	8.91
CCVC	9.08	CVVCC	8.69	CVVCC	8.72
CCVCC	6.07	CCVCC	7.24	CVC	8.48
CCVVCC	4.42	CVCC	5.01	CCVVCC	5.74
CCVV	3.96	CCVVCC	4.12	CVCCC	3.92
CVCCC	3.27	CCVV	3.31	CCVV	3.28
CVV	2.99	CVV	1.88	CCVCCC	1.99
CCVCCC	1.15	CCVCCC	1.72	CCCVC	1.57
CVVCCC	1.04	VCC	1.36	CVV	1.39
VC	0.89	CVVCCC	1.22	CCCVVC	1.25
VVC	0.88	CCCVC	1.06	CVVCCC	1.07

We specifically examined the token frequencies of those syllables directly affected by the application of the sentence-level phonological rules. Progressive voice assimilation devoiced syllable-initial fricatives. The effect of progressive voice assimilation is difficult to estimate, however, because the effect might interact with resyllabifications due to the OP: A fricative that became voiceless in syllable-initial position due to progressive voice assimilation may be in second position at the end of the derivation, that is, after all sentence-level rules have applied. In the set of lexeme syllables there were 3,291 syllables (27.36%) beginning with a voiceless fricative, i.e., [f], [s], or [x], whereas in the corpus of speech syllables there were 4,755 such syllables (28.79%). Although the relative numbers hardly differ - possibly because of the reason mentioned above -, the absolute numbers partially reflect the effect of progressive voice assimilation. Regressive voice assimilation introduced syllables ending in voiced obstruents. The occurrence of such syllables, which was 1,346 (= 11.19%) in the lexeme corpus, was 4,209 (= 25.48%) in the speech corpus. As regressive assimilation applied to syllables with voiceless final obstruents, the relative frequencies of those syllables was lower in the speech than in the lexeme corpus (7,819 (47.34%) vs. 6,930 (57.62%)).

Fusion and cliticization eliminated all the full forms of clitics and pronouns, which had a frequency of 21,293 in the lexeme syllable inventory. /n/-deletion reduced the frequency of syllables ending in /ən/ from 6.45% to 2.64% of all syllables. The proportion of syllables ending in /ə/ increased from 12.34% to 18.41%.

Because of the frequent application of external sandhi, we expected that the lexeme and speech syllable inventories would differ strongly in the distribution of syllables with different CV structures. In particular, the speech syllables should have more complex onsets than lexeme syllables. Table 7 shows that syllables without an onset appeared less frequently among the speech than the lexeme syllables. Thus, as expected, such syllables tended to gain an onset. By contrast, syllables with one or with more onset consonants appeared more frequently among the speech syllables than among the lexeme syllables.

Table 7 also shows the frequencies of syllables differing in coda complexity. One might expect speech syllables to have less complex codas, because coda consonants are often drawn into the onset of the following syllable. However, cliticization may increase the complexity of codas. As can be seen from Table 7, the frequencies of syllables with different coda types were almost identical in the two corpora (complex codas in ca. 8% of the tokens in both inventories).

Thus, in spite of the massive application of the sentence-level rules, the effects on the distribution of syllables with different CV structures were limited. Table 6b shows the token frequencies of the most common syllables. In both inventories the three most common types of CV structure are, in order of frequency, CVV, CVC, and CVVC, together accounting for more than 70% of all syllables. As mentioned, many new types of syllables were added to the inventory by application of sentence-level phonological rules. But because the token frequencies of most of these newcomers were very low, the relative frequencies of syllables with different CV structures were hardly changed.

Table 7 DISTRIBUTION OF TYPES OF ONSETS AND CODAS AMONG THE LEXEME AND THE SPEECH SYLLABLES (BOTH FROM TROUW).

type of constituent		lexeme syllables		speech syllables	
		proportion of tokens	proportion of types	proportion of tokens	proportion of types
onset					
	none	14.13%	4.23%	5.27%	2.97%
	C	76.95%	56.04%	82.90%	48.57%
	≥ CC	8.93%	39.73%	11.84%	48.46%
coda					
	none	36.41%	5.92%	44.88%	5.94%
	C	55.21%	45.83%	47.52%	46.23%
	≥ CC	8.38%	48.25%	7.60%	47.83%

The most salient difference between Tables 6a and 6b is that the CVV syllable is by far the most frequent type of syllable with respect to token frequency in all three sets, whereas this syllable type is not among the ten most frequent types with respect to type frequency. Another finding is that CV types without onset (e.g., VC, VCC, VV, VVC, etc.) are dispreferred if we look at the type frequencies but, in fact, they are relatively frequent if we consider the tokens. This means that there are some CV structures in Dutch (e.g., CVV) that do not occur in many syllable types, but the ones that have this CV structure occur with high frequency.

Table 6b CV STRUCTURES AND CORRESPONDING PROPORTION OF ALL SYLLABLE TOKENS.

CELEX lexeme syllables		TROUW lexeme syllables		TROUW speech syllables	
CV structure	**% of syllable tokens**	**CV structure**	**% of syllable tokens**	**CV structure**	**% of syllable tokens**
CVV	36.28	CVV	30.96	CVV	38.48
CVVC	16.24	CVC	21.30	CVC	23.68
CVC	16.20	CVVC	18.35	CVVC	14.75
VC	9.49	VC	8.29	CCVV	5.06
VVC	5.57	CVCC	3.58	CVCC	3.63
CVCC	3.04	CCVV	3.54	CCVC	3.23
CCVV	2.58	VVC	3.30	VC	2.68
CVVCC	2.47	CVVCC	2.29	CVVCC	1.94
CCVC	2.00	CCVC	2.23	CCVVC	1.70
CCVVC	1.57	VV	1.66	VVC	1.27
VV	1.52	CCVVC	1.51	VV	1.01
VCC	.89	VCC	.68	CCVCC	.72
CCVCC	.58	CCVCC	.58	CCVVCC	.46
CCVVCC	.39	CCVVCC	.49	CVCCC	.34
CVCCC	.30	CVCCC	.38	CCCVV	.29

CONCLUSIONS

The present study provides an estimate of the frequency of application of a number of Dutch sentence-level phonological rules. In our corpus, approximately one out of three words was affected by application of such a rule. The inventories of lexeme and speech syllable differed from each other: The frequency of certain types of syllables was reduced in the speech syllable inventory, while that of others was increased. The most important result is that the total number of syllable types was much larger in the speech than in the lexeme inventory because many types of syllables were not permitted on the word level, but occurred on the sentence level because phonotactic constraints were weakened.[9] However, because the token frequency of most of these newcomers was low, the relative token frequencies of syllables with different CV structures were very similar in the two inventories.

An unexpected, but very interesting finding was that the 500 most frequent syllable types sufficed to generate almost 85% of all syllable tokens of the CELEX corpus. A similar calculation for English using the English lexical database of CELEX revealed a comparable finding. In English, the 500 most frequent syllables cover 80% of all the syllable tokens. As mentioned in the Introduction, Levelt and Wheeldon (1994) have suggested that speakers may retrieve precompiled articulatory programs for high-frequency syllables from a mental syllabary. The finding of the present study that the large majority of the word tokens could be generated from a fairly small number of syllable types supports Levelt and Wheeldon's assumption that access to a syllabary would reduce the computational load during phonetic encoding. Thus, a mental syllabary may indeed be a device at the speaker's disposition.

The practical consequences of this study are straightforward: Inventories of lexeme syllables appear to provide a reasonable estimate of syllable frequencies in connected speech. Investigators, however, should remember that the frequencies of certain types of syllables - those affected by the application of sentence-level phonological rules - may be over- or

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[9] *In fact, this has also been acknowledged by phonologists. Some constraints on syllable structure are turned off at a higher level of speech, and thus types of syllables can be created that are not allowed for by the lexical syllabification algorithm (Booij, 1995). According to Laeufer (1995) collocational constraints are relaxed in fast speech and the general sonority-based constraints determine syllabification.*

underestimated, and that in connected speech many syllable types will occur that cannot occur at the word level. Syllables that begin with a vowel, for instance, are very likely to gain an onset. Experimenters should be careful with this kind of syllable. In general speech syllables became more complex in terms of CV structure. Special attention should also be paid to syllable-final obstruent voicing and devoicing. There are a number of voice-assimilation rules in Dutch that apply on different levels in the course of the speech production process and often change the quality of final obstruents in terms of voicing. Finally, syllables used in experiments should not constitute potential clitics because cliticization is a common phenomenon in Dutch and often leads to segmental modifications of syllables or to resyllabifications.

Finally, we wish to draw the reader's attention to the limitations of the present study. Obviously, a written text cannot be turned into spoken discourse simply by applying sentence-level phonological rules. Although the basic syntactic rules are the same, spoken and written language differ in many ways, such as sentence length and complexity (Chafe, 1992; Hayes, 1988; Kroll, 1977; Redeker, 1984). It seems unlikely that these differences entail large differences in the occurrence of contexts permitting the application of sentence-level phonological rules, but this is, of course, an empirical issue. Spoken language may include elements, such as interjections, that rarely occur in writing; hence, the frequencies of these syllables were definitely underestimated in the present study. Most importantly, sentence-level phonological rules were applied whenever permitted by the segmental context. Almost certainly, speakers use sentence-level phonological rules more sparingly. Thus, in reality the differences between lexeme and speech inventories are likely to be smaller than those described here.

REFERENCES

BAGEMIHL, B. (1995). Language games and related areas. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 697-712). Cambridge: Blackwell.

BELL, A. & HOOPER, J. B. (1978). Issues and evidence in syllabic phonology. In A. Bell & J. B. Hooper (Eds.), *Syllables and segments* (pp. 3-22). Amsterdam: North-Holland.

BERENDSEN, E. (1986). *The phonology of cliticization.* Dordrecht, Riverton: Foris.

BERG, T. (1992). Umrisse einer psycholinguistischen Theorie der Silbe [Outline of a psycholinguistic theory of the syllable]. In P. Eisenberg, H. Vater, K.-H. Ramers (Eds.), *Silbenphonologie des Deutschen* [Syllable phonology of German] (pp. 45-99). Tübingen: Narr.

BERTONCINI, J. & MEHLER, J. (1981). Syllables as units in infants' speech perception. *Infant Behavior and Development*, **4**, 247-260.

BLEVINS, J. (1995). The syllable in phonological theory. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 206-244). Cambridge: Blackwell.

BOOIJ, G. (1995). *The phonology of Dutch.* Oxford: Clarendon Press.

BOOIJ, G. & RUBACH, J. (1987). Postcyclic versus postlexical rules in lexical phonology. *Linguistic Inquiry*, **18**, 1-44.

BRADLEY, D. C., SÁNCHEZ-CASAS, R. M. & GARCÍA-ALBEA, J. E. (1993). The status of the syllable in the perception of Spanish and English. *Language and Cognitive Processes*, **8**, 197-233.

BROWMAN, C. P., & GOLDSTEIN, L. (1989). Articulatory gestures as phonological units. *Phonology*, **6**, 201-251.

BURNAGE, G. (1990). *CELEX. A guide for users.* Nijmegen: Centre for Lexical Information.

CHAFE, W. (1992). Information flow in speaking and writing. In P. Downing, S. D. Lima, & M. Noonan (Eds.), *The linguistics of literacy* (pp. 17-29). Amsterdam: Benjamins.

CHITASHVILI, R. J. & BAAYEN, R. H. (1993). Word frequency distributions. In L. Hřebíček, & G. Altmann (Eds.), *Quantitative text analysis* (pp. 54-135). Trier: Wissenschaftlicher Verlag.

CLEMENTS, G. N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston & M. E. Beckman (Eds.), *Papers in laboratory phonology I. Between the grammar and physics of speech* (pp.

283-333). Cambridge: Cambridge University Press.

COWAN, N., BRAINE, M. D. S., & LEAVITT, L. A. (1985). The phonological and metaphonological representation of speech: Evidence from fluent backward talkers. *Journal of Memory and Language*, **24**, 679-698.

CROMPTON, A. (1981). Syllables and segments in speech production. *Linguistics*, **19**, 663-716.

CUTLER, A. (1995). Spoken word recognition and production. In J. L. Miller & P. D. Eimas (Eds.), *Speech, Language, and Communication* (pp. 97-136). San Diego: Academic Press.

CUTLER, A., MEHLER, J., NORRIS, D. G., & SEGUI, J. (1986). The syllable's differing role in the segmentation of French and English. *Journal of Memory and Language*, **25**, 385-400.

DAVIS, S. (1982). Rhyme, or reason? A look at syllable-internal constituents. In M. Macaulay & O. D. Gensler (Eds.), *Proceedings of the Eighth Annual Meeting of the Berkeley Linguistics Society, 13-15 February, 1982* (pp. 525-532). Berkeley: Berkeley Linguistic Society.

DUPOUX, E. (1993). The time course of prelexical processing: The syllabic hypothesis revisited. In G. T. M. Altmann & R. Shillcock (Eds.), *Cognitive Models of Speech Processing: The Second Sperlonga Meeting* (pp. 81-114). Hillsdale: Lawrence Erlbaum.

FALLOWS, D. (1981). Experimental evidence for English syllabification and syllable structure. *Journal of Linguistics*, **17**, 309-317.

FERGUSON, C. (1976). Remarks on theories of phonological development. In W. von Raffler-Engel & Y. Lebrun (Eds.), *Baby talk and infant speech* (pp. 84-98). Amsterdam: Swets & Zeitlinger.

FERRAND, L., SEGUI, J., & GRAINGER, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, **35**, 708-723.

FOWLER, C. A., TREIMAN, R., & GROSS, J. (1993). The structure of English syllables and polysyllables. *Journal of Memory and Language*, **32**, 115-140.

FUJIMURA, O. (1975). Syllable as a unit of speech recognition. *IEEE Transactions on Acoustics, Speech, and Signal Processing*, **ASSP-23**, 82-87.

GERKEN, L. A. (1994). Young children's representations of prosodic phonology: Evidence from English-speakers' weak syllable productions. *Journal of Memory and Language*, **33**, 19-38.

GOOD, I. J. (1953). The population frequencies of species and the estimation of population parameters. *Biometrika*, **40**, 237-264.

GREENBERG, J. H., OSGOOD, C. E., & JENKINS, J. J. (1963). Memorandum concerning language universals. In J. H. Greenberg (Ed.), *Universals of language* (pp. XV-XXVII). Second edition, 1973. Cambridge, MA: MIT Press.

HAYES, D. P. (1988). Speaking and writing: Distinct patterns of word choice. *Journal of Memory and Language*, **27**, 572-585.

HOARD, J. E. (1971). Aspiration, tenseness, and syllabification in English. *Language*, **47**, 133-140.

HOMBERT, J.-M. (1986). Word games: Some implications for analysis of tone and other phonological constructs. In J. J. Ohala & J. J. Jaeger (Eds.), *Experimental phonology* (pp. 175-186). Orlando: Academic Press.

VAN DER HULST, H. (1984). *Syllable structure and stress in Dutch*. Dordrecht, Cinnaminson: Foris.

VAN DER HULST, H. & LAHIRI, A. (ms). Remarks on phonetic and phonological representations for the CELEX database.

ITÔ, J. (1986). *Syllable theory in prosodic phonology*. Amherst: University of Massachusetts Ph.D. dissertation. Published by Garland Press, New York, 1988.

ITÔ, J. (1989). A prosodic theory of epenthesis. *Natural Language and Linguistic Theory*, **7**, 217-259.

JUSCZYK, P. W. (1994). Infant speech perception and the development of the mental lexicon. In J. C. Goodman & H. C. Nusbaum (Eds.), *The development of speech perception: The transition from speech sounds to spoken words* (pp. 227-270). Cambridge, MA: MIT Press.

JUSCZYK, P. W., JUSCZYK, A. M., KENNEDY, L. J., SCHOMBERG, T., & KOENIG, N. (1995). Young infants' retention of information about bisyllabic utterances. *Journal of Experimental Psychology: Human Perception and Performance*, **21**, 822-836.

KAGER, R. (1989). *A metrical theory of stress and destressing in English and Dutch*. Dordrecht, Providence, RI: Foris.

KAGER, R. & ZONNEVELD, W. (1986). Schwa, syllables and extrametricality. *The Linguistic Review*, **5**, 197-222.

KAHN, D. (1976). *Syllable-based generalizations in English phonology*. New York: Garland, 1980.

KENSTOWICZ, M. (1994). *Phonology in generative grammar*. Cambridge, MA: Blackwell.

KIPARSKY, P. (1973). 'Elsewhere' in phonology. In S. Anderson & P.

Kiparsky (Eds.), *A Festschrift for Morris Halle* (pp. 93-106). New York: Holt, Rinehart and Winston.

KIPARSKY, P. (1982). From cyclic to lexical phonology. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations. Part I* (pp. 131-175). Dordrecht: Foris.

KIPARSKY, P. (1985). Some consequences of lexical phonology. *Phonology Yearbook*, **2**, 83-138.

KROLL, B. (1977). Combining ideas in written and spoken English: A look at subordination and coordination. In E. O. Keenan & T. L. Bennett (Eds.), *Discourse across time and space* (pp. 69-107). Los Angeles (Southern California Occasional Papers in Linguistics; 5).

KURIŁOWICZ, J. (1948). Contribution à la théorie de la syllable [Contribution to the theory of the syllable]. In J. Kuriłowicz (Ed.), *Esquisses linguistiques I* (pp. 193-220). Deuxième édition, 1973. München: Fink.

LAEUFER, C. (1995). Effects of tempo and stress on German syllable structure. *Journal of Linguistics*, **31**, 227-266.

LAHIRI, A. & KOREMAN, J. (1988). Syllable weight and quantity in Dutch. In H. Borer (Ed.), *Proceedings of the 7th West Coast Conference of Formal Linguistics 1988* (pp. 217-228). Stanford, CA: Center for the Study of Language and Information, Stanford University.

LAYCOCK, D. (1972). Towards a typology of ludlings or play-languages. *Linguistic Communications*, **6**, 61-113.

LEFKOWITZ, N. (1991). *Talking backwards, looking forwards. The French language game Verlan.* Tübingen: Narr.

LEVELT, C. C. (1994). *On the acquisition of place.* Dordrecht: ICG Printing (HIL dissertations; 8).

LEVELT, W. J. M. (1989). *Speaking. From intention to articulation.* Cambridge, MA: MIT Press.

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

LIBERMAN, I. Y., SHANKWEILER, D. FISCHER, F. W., & CARTER, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Child Psychology*, **18**, 201-212.

LINDBLOM, B. (1963). Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America*, **35**, 1773-1781.

MACKAY, D. (1970). Spoonerisms: The structure of errors in the serial order of speech. *Neuropsychologia*, **8**, 323-350.

MACKEN, M. A. (1995). Phonological acquisition. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 671-696). Cambridge: Blackwell.

MADDIESON, I. (1984). *Patterns of sound.* Cambridge: Cambridge University Press.

MEHLER, J., SEGUI, J., & FRAUENFELDER, U. (1981a). The role of the syllable in language acquisition and perception. In T. Myers, J. Laver, & J. Anderson (Eds.), *The cognitive representation of speech* (pp. 295-305). Amsterdam: North-Holland.

MEHLER, J., DOMMERGUES, J. Y., FRAUENFELDER, U., & SEGUI, J. (1981b). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior*, **20**, 298-305.

MERMELSTEIN, P. (1975). Automatic segmentation of speech into syllabic units. *Journal of the Acoustical Society of America*, **58**, 880-883.

MEYER, A. S. (1992). Investigation of phonological encoding through speech error analyses: Achievements, limitations, and alternatives. *Cognition*, **42**, 181-211.

MOHANAN, K. P. (1986). *The theory of lexical phonology.* Dordrecht: Reidel.

NESPOR, M. & VOGEL, I. (1982). Prosodic domains of external sandhi rules. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations. Part I* (pp. 225-255). Dordrecht, Cinnaminson: Foris.

NOOTEBOOM, S. (1969). The tongue slips into patterns. In A. G. Sciarone, A. J. von Essen, & A. A. van Raad (Eds.), *Nomen: Leyden Studies in Linguistics and Phonetics* (pp. 114-132). The Hague: Mouton.

NUSBAUM, H. & DEGROOT, J. (1990). The role of syllables in speech perception. In M. Ziolkowski, M. Noske, & K. Deaton (Eds.), *Papers from the 26th Regional Meeting of the Chicago Linguistic Society, Volume 2, The Parasession on the Syllable in Phonetics & Phonology* (pp. 287-317). Chicago: Chicago Linguistic Society.

PITT, M. A. & SAMUEL, A. G. (1995). Lexical and sublexical feedback in auditory word recognition. *Cognitive Psychology*, **29**, 149-188.

RAMERS, K. H. (1988). *Vokalquantität und -qualität im Deutschen* [Vowel quantity and quality in German]. Tübingen: Niemeyer.

REDEKER, G. (1984). On differences between spoken and written language. *Discourse Processes*, **7**, 43-55.

SCHILLER, N. O., MEYER, A. S., & LEVELT, W. J. M. (1997). The syllabic structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, **40**, 103-140.

SCHWARTZ, R. G. & GOFFMAN, L. (1995). Metrical patterns of words and production accuracy. *Journal of Speech and Hearing Research*, **38**, 876-888.

SELKIRK, E. O. (1982). The syllable. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations. Part II* (pp. 337-393). Dordrecht: Foris.

SELKIRK, E. O. (1984). On the major class features and syllabic theory. In M. Aronoff & R. T. Oehrle (Eds.), *Language sound structure. Studies in phonology presented to Morris Halle by his teacher and students* (pp. 107-136). Cambridge, MA: MIT-Press.

SHATTUCK-HUFNAGEL, S. (1979). Speech errors as evidence for a serial ordering mechanism in sentence production. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing* (pp. 295-342). New York: Halsted Press.

SLIS, I. H. (1984). Assimilation of voice in Dutch. In M. P. R. van den Broecke & A. Cohen (Eds.), *Proceedings of the Tenth International Congress of Phonetic Sciences* (pp. 404-410). Dordrecht, Cinnaminson: Foris.

STEMBERGER, J. P. (1982). The nature of segments in the lexicon: Evidence from speech errors. *Lingua*, **56**, 235-259.

STROOP, J. (1986). Some sandhi-phenomena in the southern Dutch dialects. In H. Andersen (Ed.), *Sandhi phenomena in the languages of Europe* (pp. 145-155). Berlin: Mouton de Gruyter.

TREIMAN, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, **15**, 49-74.

TREIMAN, R. (1986). The division between onsets and rimes in English syllables. *Journal of Memory and Language*, **25**, 476-491.

TREIMAN, R. & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

TREIMAN, R. & ZUKOWSKI, A. (1990). Toward an understanding of English syllabification. *Journal of Memory and Language*, **29**, 66-85.

TROMMELEN, M. (1984). *The syllable in Dutch. With special reference to diminutive formation*. Dordrecht, Cinnaminson: Foris.

VAISSIÈRE, J. (1981). Speech recognition programs as models of speech perception. In T. Myers, J. Laver, & J. Anderson (Eds.), *The cognitive representation of speech* (pp. 443-457). Amsterdam: North-Holland.

VENNEMANN, T. (1982). Zur Silbenstruktur der deutschen Standardsprache [On the syllable structure of standard German]. In T. Vennemann (Ed.), *Silben, Segmente, Akzente* [*Syllables, segments, accents*] (pp. 261-305).

Tübingen: Niemeyer.

VENNEMANN, T. (1994). Universelle Nuklearphonologie mit epiphänomenaler Silbenstruktur [Universal nuclear phonology with epiphenomenal syllable structure]. In K. H. Ramers, H. Vater, & H. Wode (Eds.), *Universale phonologische Strukturen und Prozesse* [*Universal phonological structures and processes*] (pp. 7-54). Tübingen: Niemeyer.

VOGEL, I. (1986). External sandhi rules operating between sentences. In H. Andersen (Ed.), *Sandhi phenomena in the languages of Europe* (pp. 55-64). Berlin: Mouton de Gruyter.

VROOMEN, J. & DE GELDER, B. (1994). Speech segmentation in Dutch: No role for the syllable. In *Proceedings of the 1994 International Conference on Spoken Language Processing, September 18 - 22, 1994, Yokohama* (pp. 1135-1138).

WHEELDON, L. R. & LEVELT, W. J. M. (1995). Monitoring the time course of phonological encoding. *Journal of Memory and Language*, **34**, 311-334.

WHITE, C. M. N. (1955). 'Backwards languages' in Africa. *Man*, **55**, 96.

WIJNEN, F., KRIKHAAR, E., & DEN OS, E. (1994). The (non)realization of unstressed elements in children's utterances: Evidence for a rhythmic constraint. *Journal of Child Language*, **21**, 59-83.

ZONNEVELD, W. (1983). Lexical and phonological properties of Dutch voicing assimilation. In M. van den Broecke, V. van Heuven, & W. Zonneveld (Eds.), *Sound structures. Studies for Antonie Cohen* (pp. 297-312). Dordrecht, Cinnaminson: Foris.

ZWITSERLOOD, P., SCHRIEFERS, H., LAHIRI, A., & VAN DONSELAAr, W. (1993). The role of syllables in the perception of spoken Dutch. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **19**, 260-271.

THE SYLLABIC STRUCTURE OF SPOKEN WORDS: EVIDENCE FROM THE SYLLABIFICATION OF INTERVOCALIC CONSONANTS

CHAPTER 3

(Slightly adapted version of article published in *Language and Speech*, 1997, **40**, 103-140)

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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., 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 (pre-vocalic) 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, i.e., 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., Engl. *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,

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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.*

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 <e>. Although it is phonetically short, a following intervocalic consonant is not ambisyllabic and there is no double spelling, e.g., *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* ['rɑ[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 co-workers (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 pre-schoolers 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* ['kɪ[k]ər] 'frog' yielding ['kɪː.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 preferrably affiliated only with the onset of the following syllable -- could be replicated using a different meta-linguistic task. Before turning to the detailed description of the experiments, we will describe the task and discuss how participants may deal with it.

Meta-linguistic 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 labelled 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 head phones. 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 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 variable (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

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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.*

of the experiments. There were twelve participants in each experiment except for Experiment 3B (15 participants) and Experiment 5 (22 participants).

EXPERIMENT 1: SYLLABIFICATION OF SYLLABLES WITH SHORT VS. LONG VOWELS

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.

Method

Stimuli. 144 bisyllabic Dutch nouns were selected as stimuli for the first experiment. There were three main categories of items. 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, e.g., *boedel* ['bu.dəl] 'possession, property', *koffie* ['kɔ[f]i] 'coffee', etc. 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, i.e., 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, i.e., 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, $MS_e = 6.99$, $p < .001$, $F_2(2,132) = 413.39$, $MS_e = 3.31$, $p < .001$). Newman-Keuls tests revealed that all differences between stimulus categories were significant ($p < .01$) by participants and items.

Table 1 RESULTS OF EXPERIMENT 1. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

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, MS_e = 0.78, $p < .01$, F_2 (1,44) = 3.17, MS_e = 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

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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.*

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, MS_e = .06, $p < .05$, F_2 (3,44) = 0.74, MS_e = .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 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

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[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,* MS_e *= 4055,* $p < .001$*,* F_2 *(2,141) = 5.82,* MS_e *= 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 not 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.*

[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).*

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: ORTHOGRAPHIC EFFECTS ON SYLLABIFICATION

The participants of Experiment 1 showed a strong tendency to close syllables with short vowels, i.e., 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.

Method

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>, e.g., *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 */ɣ/-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] 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, e.g., *tonic* ['tɔ[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*, i.e., bisyllabic word forms with a single intervocalic consonant that is graphemically represented by a geminate (e.g., *hennep* ['hɛ[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 two 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, MS_e = 0.02, $p < .05$, t_2 (24) = 1.33, MS_e = 0.04). This finding constitutes at best weak evidence for the involvement of an orthographic strategy in the syllable reversal task.

Table 2 RESULTS OF EXPERIMENT 2. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

The difference between /x/- and /ɣ/-items was significant (t_1 (1,11) = 7.03, $MS_e = 0.08$, $p < .001$, $t_2(1,24) = 7.70$, $MS_e = 0.04$, $p < .001$). 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: VOWEL QUALITY EFFECTS IN WORDS

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 (F_1 and F_2). The differences between F_1 and F_2 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.

Method

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, i.e., /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

Analysis of the response types. 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.

Table 3a RESULTS OF EXPERIMENT 3A. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

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, MS_e = 7.05, p < .001, F_2(2,141) = 3171.55, MS_e = 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 pseudo-words with final stress.

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: VOWEL QUALITY EFFECTS IN PSEUDOWORDS

Method

Stimuli. There were 192 items which could be grouped into four different categories. All items were bisyllabic pseudo-words obeying Dutch phonotactics. Stress was always on the second syllable, e.g., *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, i.e., they had a tense (long) vowel (as in *daafel* [da.'fɛl], *doofel* [do.'fɛl], *deefel* [de.'fɛl], and *diefel* [di.'fɛl]. As fillers served 96 consonant cluster items, 48 containing a lax (short) vowel in the first syllable, e.g., *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, e.g., *daanfep* [dan.'fɛp], *doonfep* [don.'fɛp], *deenfep* [den.'fɛp], and *dienfep* [din.'fɛp].

Results and Discussion

Analysis of the response types. 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.

Table 3b RESULTS OF EXPERIMENT 3B. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

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, MS_e = 2.76, p < .01, F_2 (3,44) = 2.52, MS_e = 8.02, p = .07). There were 170 open syllables responses (23.6%) to /ɑ, ɔ/-geminate items and 127 (17.6%) to /ɪ, ɛ/-items. Planned pairwise comparisons revealed that the mean proportions of open syllable responses differed significantly (p < .01) between the /ɑ, ɔ/-items and the /ɪ, ɛ/-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 /ɪ/ or /ɛ/ 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, i.e., 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 pseudo-words, i.e., 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: SYLLABIFICATION OF SCHWA SYLLABLES

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* ['ɑk.tə] 'folder', *pauze* ['pɑʊ.zə] 'pause', etc.); short vowels cannot. Neither schwa nor long vowels can precede certain types of C-clusters, e.g., non-dental 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 co-articulatory 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 F_2) 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.

Method

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, e.g., *beton* [bə'tɔn] 'concrete'. The second category of test items had the long vowel /e/ in the first syllable and a single intervocalic consonant, e.g., *dekaan* [de.'kan] 'dean'. They were called the */e/-items*. The third category comprised the */ɛ/-items*, i.e., word forms with the short vowel /ɛ/ in the first syllable and a single intervocalic consonant, which was spelled with a graphemic geminate, e.g., *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

Analysis of the response types. 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.

Table 4 RESULTS OF EXPERIMENT 4. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

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, $MS_e = 0.02$, $p < .001$, F_2(4,55) = 157.00, $MS_e = 0.04$, $p < .001$). 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 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: ITEM SET EFFECTS ON SYLLABIFICATION

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

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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, $MS_e = 0.02$, $p < 0.001$, F_2 (4,55) = 161.01, $MS_e = 0.04$, $p < 0.001$). 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.*

Experiment 1. Experiment 5 investigated whether the syllabification of geminate items depended on the composition of the entire item set.

Method

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

Analysis of the response types. 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, MS_e = 1.07, $p < .001$, F_2(1,42) = 11.46, MS_e = 0.66, $p < 0.01$), but no significant interaction of context and stimulus category (F_1 (2,40) = 1.88, MS_e = 1.07, F_2 (2,42) = 2.25, MS_e = 0.66). However, the analyses of simple effects showed a significant effect of context for the geminate items (F_1 (1, 20) = 5.18, MS_e = 1.26, $p < .05$, F_2 (1,42) = 7.32, MS_e = 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, MS_e = 1.89, p = .057, F_2(1,42) = 8.59, MS_e = 0.66, $p < 0.01$), while the consonant cluster items showed no effect of context at all.

Table 5 RESULTS OF EXPERIMENT 5. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

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

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.

EXPERIMENT 6: TASK-SPECIFIC EFFECTS ON SYLLABIFICATION

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, i.e., 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

Analyses of the response types. 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.

Table 6 RESULTS OF EXPERIMENT 6. PROPORTIONS (%) OF CLOSED AND OPEN SYLLABLE RESPONSES AND ERRORS FOR DIFFERENT ITEM CATEGORIES.

	Response syllable type		
	closed	open	error
Item category			
Geminate (n = 576)	79.2	19.4	1.4
Simple consonant (n = 576)	4.5	95.5	0.0
Consonant cluster (n = 576)	99.7	0.3	0.0

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, MS_e = 6.13, $p < .001$, F_2 (2,132) = 966.58, MS_e = 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.

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 *let-ter* 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, or 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 pseudo-words that were stressed on the second syllable. Now 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 than before a loosely connected consonant. 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 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, i.e., 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

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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, i.e., the 'pause-break' task.*

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 non-branching 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", i.e., lower-ranking constraints play no role in determining the degree of acceptability of non-optimal forms. Yet in our data there are clear indications that non-optimal forms can be non-optimal 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, 1997), 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.

REFERENCES

ADAMS, M. J. (1981). What good is orthographic redundancy? In O. J. L. Tzeng & H. Singer (Eds.), *Perception of print. Reading research in experimental psychology* (pp. 197-221). Hillsdale, NJ: Lawrence Erlbaum.

BAGEMIHL, B. (1995). Language games and related areas. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 697-712). Cambridge: Blackwell.

BAILEY, C.-J. N. (1978). *Gradience in English syllabization and a revised concept of unmarked syllabization.* Bloomington, IN: Indiana University Linguistics Club.

VAN BERGEM, D. (1995). *Acoustic and lexical vowel reduction.* Ph. D. dissertation. Amsterdam: IFOTT (Studies in language and language use; 16).

BOOIJ, G. (1995). *The phonology of Dutch.* Oxford: Clarendon Press.

BOOIJ, G. E., HAMANS, C., VERHOEVEN, G., BALK, F,. & van MINNEN, CH. H. (1979). *Spelling.* Groningen: Wolters-Noordhoff.

BRADLEY, D. C., SÁNCHEZ-CASAS, R. M., & GARCÍA-ALBEA, J. E. (1993). The status of the syllable in the perception of Spanish and English. *Language and Cognitive Processes,* **8**, 197-233.

BROWMAN, C. P. & GOLDSTEIN, L. (1992). "Targetless" schwa: An articulatory analysis. In G. J. Docherty & D. R. Ladd (Eds.), *Papers in laboratory phonology II. Gesture, segment, prosody* (pp. 26-56). Cambridge: Cambridge University Press.

COWAN, N., LEAVITT, L. A., MASSARO, D. W., & KENT, R. D. (1982). A fluent backward talker. *Journal of Speech and Hearing Research,* **25**, 48-53.

COWAN, N., BRAINE, M. D. S., & LEAVITT, L. A. (1985). The phonological and metaphonological representation of speech: Evidence from fluent backward talkers. *Journal of Memory and Language,* **24**, 679-698.

CROMPTON, A. (1981). Syllables and segments in speech production. *Linguistics,* **19**, 663-716.

DELL, G. (1986). A spreading-activation theory of retrieval in speech production. *Psychological Review,* **93**, 283-321.

DERWING, B. L. (1992). A 'pause-break' task for eliciting syllable boundary judgements from literate and illiterate speakers: Preliminary results for five diverse languages. *Language and Speech,* **35**, 219-235.

FALLOWS, D. (1981). Experimental evidence for English syllabification and syllable structure. *Journal of Linguistics*, **17**, 309-317.

FOWLER, C. A., TREIMAN, R. & GROSS, J. (1993). The structure of English syllables and polysyllables. *Journal of Memory and Language*, **32**, 115-140.

GIEGERICH, H. J. (1992). *English phonology. An introduction.* Cambridge: Cambridge University Press.

GILLIS, S. & DE SCHUTTER (1996). Intuitive syllabification: Universals and language specific constraints. *Journal of Child Language*, **23**, 487-514.

GUSSENHOVEN, C. (1986). English plosive allophones and ambisyllabicity. *Gramma*, **10**, 119-141.

HALLE, M. & MOHANAN, K. P. (1985). Segmental phonology of modern English. *Linguistic Inquiry*, **16**, 57-116.

HOARD, J. E. (1971). Aspiration, tenseness, and syllabification in English. *Language*, **47**, 133-140.

HOMBERT, J. M. (1973). Speaking backwards in Bakwiri. *Studies in African Linguistics*, **4**, 227-236.

HOMBERT, J. M. (1986). Word games: Some implications for analysis of tone and other phonological constructs. In J. J. Ohala & J. J. Jaeger (Eds.), *Experimental phonology* (pp. 175-186). Orlando: Academic Press.

HOOLE, P., MOOSHAMMER, C., & TILLMANN, H. G. (1994). Kinematic analysis of vowel production in German. *Proceedings of the third International Conference on Spoken Language Processing* (pp. 53-56) (ICSLP 1994), Yokohama.

VAN DER HULST, H. (1984). *Syllable structure and stress in Dutch.* Dordrecht, Cinnaminson: Foris.

VAN DER HULST, H. (1985). Ambisyllabicity in Dutch. In H. Bennis & F. Beukema (Eds.), *Linguistics in the Netherlands 1985* (pp. 57-66). Dordrecht, Cinnaminson: Foris.

ITÔ, J. (1989). A prosodic theory of epenthesis. *Natural Language and Linguistic Theory*, **7**, 217-259.

JAKIMIK, J., COLE, R. A., & RUDNICKY, A. I. (1985). Sound and spelling in spoken word recognition. *Journal of Memory and Language*, **24**, 165-178.

KAGER, R. (1989). *A metrical theory of stress and destressing in English and Dutch.* Dordrecht, Providence, RI: Foris.

KAGER, R. (1992). Dutch schwa in moraic phonology. In M. Ziolkowski, M. Noske, & K. Deaton (Eds.), *Papers from the 26th Regional Meeting of the Chicago Linguistic Society. Vol. 2. The Parasession on the Syllable in*

Phonetics & Phonology (pp. 241-255). Chicago: Chicago Linguistic Society.

KAGER, R. & ZONNEVELD, W. (1985-1986). Schwa, syllables, and extrametricality in Dutch. *The Linguistic Review*, **5**, 197-221.

KAHN, D. (1976). *Syllable-based generalizations in English phonology*. Ph. D. dissertation. New York: Garland, 1980.

KOOPMANS-VAN BEINUM, F. J. (1980). *Vowel contrast reduction. An acoustic and perceptual study of Dutch vowels in various speech conditions*. Ph. D. dissertation. Amsterdam: Academische Pers B. V.

LAHIRI, A. & KOREMAN, J. (1988). Syllable weight and quantity in Dutch. In H. Borer (Ed.), *Proceedings of the 7th West Coast Conference on Formal Linguistics* (pp. 217-228). Stanford, CA: Center for the Study of Language and Information.

LASS, R. (1976). *English phonology and phonological theory. Synchronic and diachronic studies*. Cambridge: Cambridge University Press.

LEFKOWITZ, N. (1991). *Talking backwards, looking forwards. The French language game Verlan*. Tübingen: Narr.

LEHISTE, I. (1972). The timing of utterances and linguistic boundaries. *Journal of the Acoustical Society of America*, **51**, 2018-2024.

LEVELT, W. J. M. (1989). *Speaking. From intention to articulation*. Cambridge, MA: MIT Press.

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

LEVIN, J. (1985). *A metrical theory of syllabicity*. Ph. D. dissertation, Massachusetts Institute of Technology, Cambridge, MA.

MCCARTHY, J. J. & PRINCE, A. S. (1993). *Prosodic morphology I: constraint interaction and satisfaction*. Manuscript, University of Massachusetts, Amherst, and Rutgers University, New Brunswick, NJ. To appear as Linguistic Inquiry Monograph. Cambridge, MA: MIT Press.

MCQUEEN, J. M., NORRIS, D., & CUTLER, A. (1994). Competition in spoken word recognition: Spotting words in other words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **20**, 621-638.

MEHLER, J., DOMMERGUES, J. Y., FRAUENFELDER, U., & SEGUI, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior*, **20**, 298-305.

MEYER, A. S. (1997). Word form generation in language production. In W. Hulstijn, H. Peters, & P. van Lieshout (Eds.), *Speech production: Motor control, brain research and fluency disorders*. Amsterdam: Elsevier.

NAKATANI, L. H. & DUKES, K. D. (1977). Locus of segmental cues for word juncture. *Journal of the Acoustical Society of America*, **62**, 714-719.

NOOTEBOOM, S. G. (1972). *Production and perception of vowel duration. A study of durational properties of vowels in Dutch.* Ph. D. dissertation. University of Utrecht.

NORRIS, D. (1994). Shortlist: A connectionist model of continuous speech recognition. *Cognition*, **52**, 189-234.

PIERREHUMBERT, J. & NAIR, R. (1995). Word games and syllable structure. *Language and Speech*, **38**, 77-114.

POLS, L. G. W. (1977). *Spectral analysis and identification of Dutch vowels in mono-syllabic words.* Ph. D. dissertation. Vrije Universiteit te Amsterdam.

PULGRAM, E. (1970). *Syllable, word, nexus, cursus.* The Hague & Paris: Mouton.

RAMERS, K. H. (1988). *Vokalquantität und -qualität im Deutschen* [*Vowel quantity and quality in German*]. Tübingen: Niemeyer.

RAMERS, K. H. (1992). Ambisilbische Konsonanten im Deutschen [Ambisyllabic consonants in German]. In P. Eisenberg, K. H. Ramers, & H. Vater (Eds.), *Silbenphonologie des Deutschen* [*Syllable phonology of German*] (pp. 246-283). Tübingen: Narr.

ROELOFS, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, **35**, 854-876.

ROELOFS, A. & MEYER, A. S. (in press). Metrical structure in planning the production of spoken words. *Journal of Experimental Psychology: Learning, memory, and Cognition.*

SCHILLER, N. O. (submitted). The effect of visually masked syllable primes on the naming latencies of words and pictures. *Journal of Memory and Language.*

SCHILLER, N. O., MEYER, A. S., BAAYEN, R. H. & LEVELT, W. J. M. (1996). A comparison of lexeme and speech syllables in Dutch. *Journal of Quantitative Linguistics*, **3**, 8-28.

DE SCHUTTER, G. & COLLIER, R. (1986). Intuïtieve syllabisering in het Nederlands [Intuitive syllabification in Dutch]. *De Nieuwe Taalgids*, **79**, 441-452.

DE SCHUTTER, G. & GILLIS, S. (1994). Intuïtieve syllabisering in de taalverwerving: een vergelijking van vijf- en achtjarigen [Intuitive syllabification in language acquisition: A comparison between five and eight year olds]. *Antwerp Papers in Linguistics*, **80**.

SEIDENBERG, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII. The psychology of reading* (pp. 245-263). Hillsdale, NJ: Lawrence Erlbaum.

SEIDENBERG, M. S. & TANENHAUS, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human, Learning and Memory*, **5**, 546-554.

SELKIRK, E. O. (1982). The syllable. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations. Part II* (pp. 337-383). Dordrecht: Foris.

SHATTUCK-HUFNAGEL, S. (1979). Speech errors as evidence for a serial-ordering mechanism in sentence production. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp. 295-342). Hillsdale, NJ: Erlbaum.

SHATTUCK-HUFNAGEL, S. (1983). Sublexical units and suprasegmental structure in speech production planning. In P. F. MacNeilage (Ed.), *The production of speech* (pp. 109-136). New York: Springer.

SLIS, I. H. & VAN HEUGTEN, M. (1989). Voiced-voiceless distinction in Dutch fricatives. In H. Bennis & A. van Kemenade (Eds.), *Linguistics in the Netherlands 1989* (pp. 123-132). Dordrecht, Providence, RI: Foris.

TREIMAN, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, **15**, 49-74.

TREIMAN, R. (1986). The division between onsets and rimes in English syllables. *Journal of Memory and Language*, **25**, 476-491.

TREIMAN, R. & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

TREIMAN, R., FOWLER, C. A., GROSS, J., BERCH, D. & WEATHERSTON, S. (1995). Syllable structure or word structure? Evidence for onset and rime units with disyllabic and trisyllabic stimuli. *Journal of Memory and Language*, **34**, 132-155.

TREIMAN, R. & KESSLER, B. (1995). In defense of an onset-rime syllable structure for English. *Language and Speech*, **38**, 127-142.

TREIMAN, R. & ZUKOWSKI, A. (1990). Toward an understanding of English syllabification. *Journal of Memory and Language*, **29**, 66-85.

TREIMAN, R. & ZUKOWSKI, A. (1996). Children's sensitivity to syllables, onsets, rimes, and phonemes. *Journal of Experimental Child Psychology*, **61**, 193-215.

TROMMELEN, M. (1984). *The syllable in Dutch. With special reference to* *diminutive formation*. Dordrecht, Cinnaminson: Foris.

TRUBETZKOY, N. S. (1939). *Grundzüge der Phonologie* [*Characteristics of phonology*]. 6. Auflage, 1977. Göttingen: Vandenhoeck & Ruprecht.

VENNEMANN, T. (1970). The German velar nasal. A case for abstract phonology. *Phonetica*, **22**, 65-81.

VENNEMANN, T. (1982). Zur Silbenstruktur der deutschen Standardsprache. In T. Vennemann (Ed.), *Silben, Segmente, Akzente* [*Syllables, segments, accents*] (pp. 261-305). Tübingen: Niemeyer.

VENNEMANN, T. (1986). *Neuere Entwicklungen in der Phonologie [More recent developments in phonology*]. Berlin, New York, Amsterdam: Mouton de Gruyter.

VENNEMANN, T. (1994). Universale Nuklearphonologie mit epiphänomenaler Silbenstruktur [Universal nuclear phonology with epi-phenomenal syllable structure]. In K. H. Ramers, H. Vater & H. Wode (Eds.), *Universale phonologische Strukturen und Prozesse* [*Universal phonological structures and processes*] (pp. 7-54). Tübingen: Niemeyer.

WIESE, R. (1988). *Silbische und lexikalische Phonologie. Studien zum Chinesischen und Deutschen* [*Syllabic and lexical phonology. Studies in Chinese and German*]. Tübingen: Niemeyer.

WIESE, R. (1996). *The phonology of German*. Oxford: Clarendon Press.

ZONNEVELD, W. (1993). Schwa, superheavies, stress and syllables in Dutch. *The Linguistic Review*, **10**, 61-110.

ZWITSERLOOD, P., SCHRIEFERS, H., LAHIRI, A., & VAN DONSELAAR, W. (1993). The role of syllables in the perception of spoken Dutch. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **19**, 260-271.

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	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

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

Appendix H EXPERIMENTAL CONSONANT CLUSTER ITEMS IN EXPERIMENT 3A.

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

Appendix I EXPERIMENTAL GEMINATE ITEMS (PSEUDO-WORDS 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 (PSEUDO-WORDS 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 (PSEUDO-WORDS 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[a]
genot	legaat	buffet[a]
belang	delikt	suppoost[a]

[a] *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

THE EFFECT OF VISUALLY MASKED SYLLABLE PRIMES ON THE NAMING LATENCIES OF WORDS AND PICTURES

CHAPTER 4

(Manuscript submitted for publication in *Journal of Memory and Language*)

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ABSTRACT

This study investigates the role of the syllable in Dutch speech production. In a series of four experiments the effect of visually masked syllable primes on the naming latencies of words and pictures was investigated. Targets either had clear syllable boundaries and began with a CV syllable (e.g., *fa.kir*) or a CVC syllable (e.g., *fak.tor*), or their syllable boundary was ambiguous, in which case they began with a CV[C] syllable (e.g., *fa[kk]el*). In the syllable match condition, bisyllabic Dutch nouns were preceded by syllable primes that were identical to the target word's first syllable. In the syllable mismatch condition, the syllable prime was one segment shorter or longer than the target word's first syllable. A neutral condition was designed to determine the direction of the priming effects (facilitation or inhibition). None of the four production experiments showed any syllable priming effect. Instead, all related primes facilitated the naming of the target words significantly, i.e., the priming effect was independent of the syllabic structure of prime and target. It is concluded that the syllable does not play a functional role in the process of phonological encoding in Dutch. Since the size of the facilitation effect increased with increasing overlap between prime and target, the priming effect is accounted for by a segmental overlap hypothesis.

INTRODUCTION

Psycholinguistic evidence suggests that the syllable may play an important role in speech perception and production, at least in some languages. In speech perception, recent research has shown that sublexical units such as the syllable can be crucial in speech segmentation and recognition (for recent reviews see Dupoux, 1993; Nusbaum & DeGroot, 1990; Segui, Dupoux, & Mehler, 1990). Using an auditory syllable monitoring task Mehler, Dommergues, Frauenfelder, and Segui (1981) showed that French participants were faster in detecting the target *pa* when it corresponded to the first syllable of the stimulus word, as e.g., in *pa.lace*, than when it did not, as e.g., in *pal.mier.*[1] Similarly, *pal* was detected faster in *pal.mier* than in *pa.lace*. Since the first three segments were identical in both stimuli, the resulting effect could only be explained by the differences in syllable structure. This syllable monitoring effect has been interpreted as evidence for syllables being used as sublexical units of speech perception in French. This conclusion was further supported by Pallier, Sebastián-Gallès, Felguera, Christophe, and Mehler (1993) showing that French as well as Spanish participants could focus their attention on specific syllable positions. They were faster in detecting a phoneme target in an expected syllable position than in an unexpected position, and this effect was independent of the serial position of the target within the carrier word.

Morais, Content, Cary, Mehler, and Segui (1989) found a syllable effect testing illiterate and ex-illiterate Portuguese participants. Sebastián-Gallès, Dupoux, Segui, and Mehler (1992) replicated the syllable monitoring effect found in French with Catalan materials, and Bradley, Sánchez-Casas, and García-Albea (1993) replicated the result for Spanish. However, Cutler, Mehler, Norris, and Segui (1986) could not replicate the effect with English materials. This failure to replicate has been accounted for in terms of differences in syllable structure between Romance languages, such as French or Spanish, and Germanic languages, such as English or Dutch. Whereas Romance languages have relatively clear syllable boundaries (but see Kearns, Frauenfelder, & Content, in preparation), syllable boundaries are often ambiguous in Germanic languages due to ambisyllabicity. In the Dutch word *fakkel* /fɑ[k]əl/

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[1] *Throughout the article, syllable boundaries are marked by dots and ambisyllabic consonants appear between square brackets.*

('torch'), for instance, the intervocalic /k/ belongs to the first and second syllable at the same time, i.e., it is ambisyllabic (Booij, 1995). Furthermore, Germanic languages exhibit a greater variety of syllable structures than Romance languages.

For Dutch, being similar in syllable structure to English, Zwitserlood, Schriefers, Lahiri, and van Donselaar (1993) obtained a syllable monitoring effect. However, Vroomen and de Gelder (1994) could not replicate the effect and concluded that there is no evidence for a syllable monitoring effect in Dutch when morphological complexity is controlled for. Likewise, Cutler (in press) did not find a crossover syllabic effect when Dutch listeners were exposed to the original materials of the Mehler et al. (1981) study in a syllable monitoring experiment. Furthermore, McQueen (submitted) argues that the results obtained by Zwitserlood et al. (1993) are compatible with the *possible-word constraint* according to which the speech input should be segmented in a way such that the output is a string of possible words in the language (Norris, McQueen, Cutler, & Butterfield, submitted). Therefore, it may be doubted that the syllable is used as a processing unit in Dutch speech perception. Thus, while the syllable has clearly been shown to be used as a processing unit in speech perception in languages having unambiguous syllable structures, the syllable does not seem to play a functional role in the perceptual system of languages with ambiguous syllable boundaries.

In speech production, there is some evidence for the role of the syllable. It has often been claimed that segmental speech errors are sensitive to syllable structure, i.e., onsets exchange with other onsets, codas exchange with other codas, etc. (for English see MacKay, 1970; Shattuck-Hufnagel, 1979; Stemberger, 1982; for Dutch see Nooteboom, 1969; for German see Berg, 1988; but see also Shattuck-Hufnagel, 1987, 1992 and for a critical review Meyer, 1992). Studies on the tip-of-the-tongue (TOT) experience showed that participants are often able to report the number of syllables of the target word when they are in a TOT state (Burke, MacKay, Worthley, & Wade, 1991; Lovelace, 1987). However, as Brown (1991) pointed out, this may at least partly be due to the fact that the chance guessing probabilities are relatively high because the number of syllables of a word is quite restricted.

Reaction time studies have yielded inconsistent results with respect to the syllable's role in speech production. Klapp, Anderson, and Berrian (1973) found that English five-letter words were named significantly faster when they were monosyllabic than when they were bisyllabic. Other researchers did not find such an effect (Forster & Chambers, 1973; Frederiksen & Kroll, 1976). Jared and Seidenberg (1990) found that the number of syllables only affected the naming latencies of low-frequency words. Furthermore, when words were presented syllable by syllable (rather than as units) in a word naming task, Jared and Seidenberg (1990) obtained an increase in the naming latencies of high- and low-frequency exception words. This suggests that the production of these words normally takes into account information that goes beyond the boundaries of individual syllables. Syllabic presentation had no effect for regular words. Based on the negative effect of syllabic presentation for low-frequency exception words, the authors argued that polysyllabic words are not generated on a syllable-by-syllable basis.

From meta-linguistic tasks, however, there is ample evidence suggesting that syllables may be functional units in speech production. Syllables are one of the linguistic units that are preferrably manipulated in naturally occurring word games (Hombert, 1986; Lefkowitz, 1991; see Bagemihl, 1995 for a review) and in backward talking (Cowan, Leavitt, Massaro, & Kent, 1982; Cowan, Braine, & Leavitt, 1985). Under laboratory conditions certain aspects of syllable structure and syllabification have been investigated revealing further evidence for the syllable as a psycholinguistic (processing) unit (Bruck, Treiman, & Caravolas, 1995; Fallows, 1981; Fowler, Treiman, & Gross, 1993; Gillis & de Schutter, 1996; Schiller, Meyer, & Levelt, 1997; Treiman, 1983, 1986; Treiman & Danis, 1988; Treiman, Fowler, Gross, Berch, & Weatherston, 1995; Treiman & Zukowski, 1990, 1996; Wheeldon & Levelt, 1995).

In Levelt's (1992, 1993; Levelt & Wheeldon, 1994) model of phonological encoding syllabification is a relatively late process during speech production. Syllables are created during *segment-to-frame association*, i.e., when individual segments that are unspecified for syllable position are associated to metrical frames, i.e., ordered strings of syllable slots marked for stress. This association process precedes overt articulation and is based on general syllabification rules respecting, e.g., the *Onset Principle* (Kahn, 1976; Itô, 1989) and the *Sonority Sequencing Generalization* (Selkirk, 1984). The resulting phonetic surface syllables are called *speech syllables* (Schiller, Meyer, Baayen, & Levelt, 1996).

Baumann (1995) investigated the time course of syllabification during word form encoding in Dutch. In a series of priming experiments using a semantic-associate learning task she studied the influence of interfering auditory stimuli on the production of different types of verb forms. For late SOAs, i.e., 150 or 300 ms after stimulus onset, Baumann predicted a syllable match effect, i.e., /ko/ should facilitate the production of /ko.kən/ ('to cook') and /ko.kət/ ('cook it [sg.]') more than /kok/, and similarly should /kok/ yield larger facilitation effects than /ko/ for /kok.tə/ ('cooked [sg.]') and /kok.tət/ ('cook it [pl.]'). However, Baumann never obtained the expected pattern of results. In all of her experiments there were significant facilitation effects when verb form targets were preceded by phonologically related syllable primes (as compared to an unrelated and a neutral control condition), but there was no clear relationship between the syllabic structure of the prime and the target.

Wheeldon and Levelt (1995), however, found evidence that the syllable plays a role in the self-monitoring of Dutch word production. In an experiment where participants monitored their own inner speech for certain segments, they were faster in detecting onset targets in word-initial position than in second syllable initial position. This result confirms earlier data showing that phonological encoding proceeds from left to right (Meyer, 1990, 1991; Meyer & Schriefers, 1991; see also van Turennout, Hagoort, & Brown, 1997). Using a syllable monitoring task of inner speech, Wheeldon and Levelt were able to show that Dutch participants were faster to monitor syllable targets when the target matched the first syllable of the carrier word than when it did not. Thus, they replicated the syllable match effect found in speech perception for Romance languages (Bradley et al., 1993; Mehler et al., 1981; Morais et al., 1989; Sebastián-Gallès et al., 1992) in the production of speech for Dutch. In their third experiment, Wheeldon and Levelt (1995) investigated the time course of segment-to-frame association using a phoneme monitoring task. Participants were asked to monitor for one of the four consonants in a CVC.CVC word. Monitoring latencies increased from left to right across target positions. These experimental results were taken as evidence for the left-to-right assignment of segments to the first syllable of a word and for the fact that the encoding of the first syllable is generally completed before the encoding of the second syllable.

Speech syllables are conceived of as articulatory motor units in Levelt's model of speech production. Crompton (1981) and later Levelt (1989) assume that there is a library of articulatory routines for syllables that is accessed during the process of speech production. Levelt and Wheeldon

(1994) further developed this idea into a so-called *mental syllabary*. Instead of generating the sound representation of a word form on the basis of segmental information coded at the phonological level, they assume that speech syllable specifications can be used to access precompiled syllabic motor programs in a mental syllabary. Access to such a syllabary could greatly reduce the computational load of the speech production system relative to a segment-by-segment assembly of articulatory programs. A lexico-statistical analysis of the Dutch, German, and English syllable inventories showed that 85% of all syllable tokens in Dutch and German and 80% of all syllable tokens in English can be covered by the 500 most frequent syllable types in the respective language (see Figure 1), which makes the idea of a separate store for (high-frequency) syllables very attractive (Schiller et al., 1996).

Ferrand, Segui, and Grainger (1996) studied the effect of masked syllable primes in a word naming task with French materials. They obtained reliable facilitation in word, nonword, and picture naming when prime and target shared the first syllable relative to a condition where they shared a string of segments of equal length that was either longer or shorter than the first syllable. In a control experiment using a visual lexical decision task, i.e., a task that could be performed without output of the phonological form of the target word, the syllable priming effect disappeared. This supported their hypothesis that the syllable priming effect arises during the creation of form representations required for overt word naming. Ferrand et al. (1996) concluded that the syllable is a functional unit in speech production.

Given the existing evidence for the role of the syllable in French speech *perception*, this result may not come as a surprise. However, recently Ferrand, Segui, and Humphreys (in press) replicated these results with English materials. Syllable structure in English is less clear than in French because English has ambisyllabic consonants, e.g., the intervocalic /n/ in a word like *tonic* /tɔ[n]ɪk/. Ferrand et al. (in press) hypothesized that CV and CVC primes (e.g., *to* and *ton*) should not yield significantly different priming effects for CV[C] targets such as *tonic*, whereas the naming of CVC targets such as *tonsil* /tɔn.sɪl/ should be facilitated only by a CVC but not by a CV prime. This hypothesis was confirmed by the data. In a lexical decision task the syllable priming effect disappeared. Furthermore, Ferrand et al. (in press) showed that English CV target words such as *tomato* /tɔ.mɑː.toʊ/ could be primed with CV but not with CVC primes.

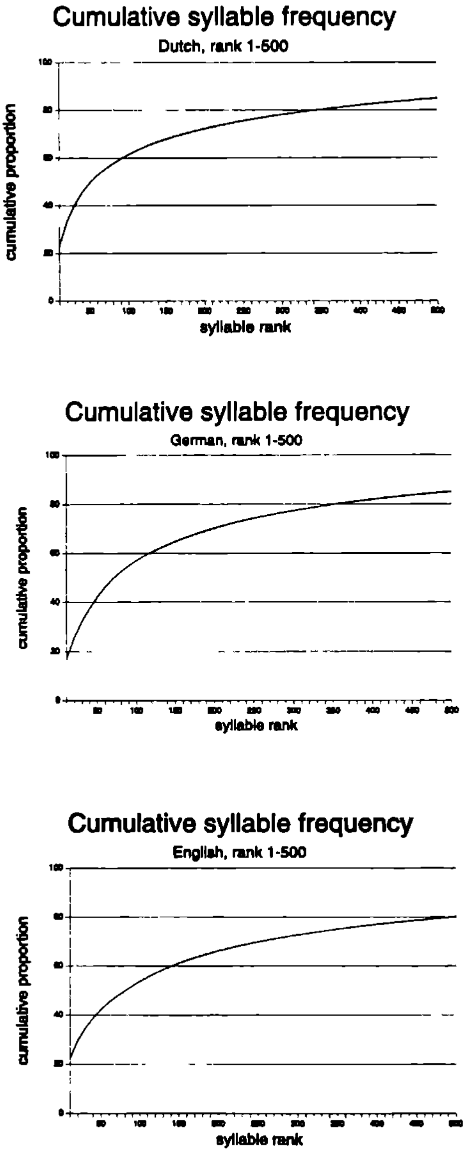

Figure 1 *Cumulative syllable frequencies of the 500 most frequent syllables in Dutch, German, and English.*

The aim of the present study is twofold. First, we would like to know whether the syllable plays a functional role in the production of Dutch. Dutch is similar to English with respect to syllable structure. Based on the results obtained for English (Ferrand et al., in press), one might expect a syllable priming effect for Dutch. Baumann's (1995) study, however, did not show such an effect. A possible reason why Baumann (1995) did not find a syllable priming effect in Dutch is that her interfering stimuli were not masked (Forster, 1987; Humphreys, Evett, Quinlan, & Besner, 1987). Maybe small syllable match effects were overruled by strategic effects. Therefore, this study applies the masked priming paradigm to investigate the effect of syllable primes in three word and one picture naming experiment with Dutch materials.

Second, if there is a syllable priming effect in Dutch, the masked syllable priming paradigm might be used to find out more about the representation of syllable structure and the syllable affiliation of intervocalic consonants in Dutch, especially with respect to ambisyllabic consonants. Approximately 8% of all Dutch words (type frequency) include ambisyllabic consonants such as the intervocalic /k/ in *fakkel* /fɑ[k]əl/ ('torch'). However, as opposed to English, ambisyllabic consonants are almost always marked in the spelling by double consonants. Evidence from syllabification experiments shows that native speakers of Dutch generally affiliate intervocalic consonants in a word like *fakkel* with both the preceding and the following syllable which supports the ambisyllabicity hypothesis (Schiller et al., 1997). Therefore, it might be hypothesized that *fa* and *fak* both match the first syllable of the target *fakkel* equally well and should thus yield similar priming effects for CV[C] targets (Ferrand et al., in press).

THE EXPERIMENTS

All experiments reported below made use of the masked priming paradigm. The naming of words can be facilitated when the target is immediately preceded by the brief exposure (usually between 20 and 60 ms) of a visually masked prime that is orthographically and/or phonologically related to the target (Ferrand, Grainger, & Segui, 1994; Forster & Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987; Grainger & Ferrand, 1996). Masking the primes has the advantage to minimize the possibility of task-specific strategic effects (Ferrand et al., 1994; Forster, 1987, 1993; Forster & Davis, 1991; Forster et al., 1987; Grainger & Ferrand, 1996; Humphreys et al., 1987). Experiments 1, 3, and 4 involved a word naming task and Experiment 2 a picture naming task. The main dependent variable was the naming latency, i.e., the interval between the onset of target presentation and speech onset. The first syllable of the target words had one of the following three CV structures: CV, e.g., FAKIR /fa.kir/ ('id.') (CV targets hereafter), CVC, e.g., FAKTOR /fɑk.tɔr/ ('factor') (CVC targets hereafter), or CV[C], e.g., FAKKEL /fɑ[k]əl/ ('torch') (CV[C] targets hereafter). The materials were obtained from the CELEX (CEntre for LEXical information) lexical database. In each experiment, three different kinds of primes were used. Related primes consisted of CV and CVC syllables that were identical to the beginning of a target word followed by a number of hash marks (e.g., fa#### or fak### for the target FAKTOR). Depending on the CV structure of the target, the prime either matched the first syllable of the target word (syllable match condition), or it was one segment shorter or longer than the target's first syllable (syllable mismatch condition). In addition, there was a neutral baseline condition (e.g., %&$###).

EXPERIMENT 1: WORD NAMING WITH CV, CVC, AND CV[C] TARGETS

In Experiment 1 the effect of CV and CVC primes on CV, CVC and CV[C] target words (e.g., KANO ('canoe'), KAKTUS ('cactus'), and KAPPER ('hair dresser'), respectively) was tested. CV and CVC targets had clear syllable boundaries, whereas the syllable structure was ambiguous in CV[C] targets. If there is a syllable priming effect in Dutch, CV but not CVC primes should facilitate the naming of CV targets. Similarly should CVC primes yield facilitation for CVC targets, but there should be no effect from CV primes. On the basis of the results obtained by Ferrand et al. (in press) for ambisyllabic target words in English, both CV and CVC primes should facilitate the naming of CV[C] targets but there should be no significant difference between the two priming condition.

Method

Procedure. Participants were tested individually. They sat in front of a computer screen in a sound-proof darkened room. The computer screen was a Samtron SC-428 TXL with a refresh rate of 60 Hz, i.e., the interval to build up a whole frame on the screen was 16.7 ms. The four-field masking procedure used here was adopted from Ferrand et al. (1996, in press). Each trial sequence began with a forward mask followed by a prime, a backward pattern mask, and the target word (see Figure 2).

type of stimulus	**syllable match condition**	**syllable mismatch condition**	**neutral control condition**	**exposure duration**
forward mask	######	######	######	500 ms
prime	fil###	fi####	%&$###	50 ms
backward mask	######	######	######	17 ms
target	FILTER	FILTER	FILTER	max. 2000 ms

Figure 2 *Sequencing of the stimuli in the masked priming paradigm used in the experiments of this study (in Experiment 2 the target word was replaced by a target picture).*

The four visual stimuli were presented in rapid succession (ISI = 0 ms), each stimulus being superimposed on the previous one. The forward pattern mask consisted of a row of hash marks (e.g., ######), which appeared for 500 ms in the center of the screen. The number of hash marks was equal to the number of letters of the target word. Then the prime was presented in lower-case letters for 50 ms. The length of the primes was identical to the length of the target words. After the presentation of the prime, the row of hash marks appeared again for 17 ms. Then the target word was presented and remained on the screen until a response was given. When no response was given within 2000 ms, the target disappeared. Targets were displayed in upper-case letters (e.g., KAKTUS) to reduce the visual overlap between prime and target. Masks, primes, and targets were presented in a nonproportional font (i.e., Courier). All items appeared in the center of the screen as white characters on black background. Each upper-case character of the target word covered approximately 0.40° of visual angle from the viewing distance of 100 cm. Target words were between four and seven letters in length subtending between 1.6° and 2.8° of visual angle. Participants were instructed to fixate the hash marks at the beginning of a trial sequence and to name the word in capital letters as fast and as accurately as they could.

Participants were not informed about the presence of the prime. Naming latencies were measured by means of a voice key (Sennheiser ME 40 microphone), which was activated at the onset of target presentation. One second after the voice key was triggered, the next trial sequence started. The presentation of the trial sequences was controlled by NESU (New Experimental Set Up). Responses were recorded on DAT for subsequent evaluation of the voice key measurements. A response was considered an error when it exceeded the time-out of 2000 ms, when it included a disfluency, when a wrong name was produced, or when the voice key was triggered incorrectly. Incorrect responses were excluded from the reaction time analyses.

After the completition of each experiment post hoc tests of prime visibility were conducted to assess the amount of perceptual awareness of the primes. In an adapted version of the prime visibility test used by Brown and Hagoort (1993), participants carried out a forced-choice recognition task. Syllable primes were presented under the same masking conditions as in the naming experiments, but instead of a word or a picture target the backward pattern mask was immediately followed by four different syllables which appeared separated by two blanks in a row in the center of the screen. One of the four syllables was the syllable prime, the others were foils. Participants were asked to identify and name the syllable prime from the set of these four syllables.

Materials. The entire set of target words consisted of 54 monomorphemic bisyllabic Dutch nouns (see Appendix A), 18 in each of the three target categories, i.e., CV, CVC, and CV[C] words. The mean frequency of occurrence per one million word forms was 16.3 for the CV targets, 17.1 for the CVC targets, and 6.0 for the CV[C] targets as determined by CELEX.

There were two types of related primes either corresponding to the first two letters of a target word (CV primes) or to the first three letters of a target word (CVC primes). In addition, there was a neutral control prime consisting of the three characters `%&$`. Related and neutral primes were followed by a number of hash marks such that primes and targets were always of the same length. To give an example, in the syllable match condition the CVC target `KAKTUS` was preceded by a CVC prime (e.g., `kak### - KAKTUS`), in the syllable mismatch condition by a CV prime (e.g., `ka#### - KAKTUS`), and in the control condition by a neutral prime (e.g., `%&$### - KAKTUS`).

Design. Experiment 1 had a within-participants design. Participants received two practice and three test blocks. In a practice block each target word was presented once preceded by a fixation cross. In a test block each target appeared once in the three priming conditions, i.e., once preceded by a CV prime, once preceded by a CVC prime, and once preceded by a neutral prime. Items were randomized individually for each participant within blocks. There was a self-paced pause between each block.

Participants. 18 participants from the pool of participants of the Max Planck Institute for Psycholinguistics in Nijmegen took part in Experiment 1 in exchange for pay. All participants were native speakers of Dutch and had normal or correct-to-normal vision.

Results

Naming latencies shorter than 300 ms and longer than 1000 ms were counted as errors (less than 1% of the data). There were 1.59% errors altogether. The mean naming latencies and error rates are summarized in Table 1 and Figure 3. An ANOVA was run with Target Structure (CV, CVC, or CV[C]), Prime Structure (CV, CVC, or neutral), and Block (1, 2, or 3) entered as main factors. F values are reported separately for participants (F_1) and items (F_2).

The main effect of Block was not significant (F_1 (2,34) = < 1; F_2(2,102) = 1.76, n.s.). Block neither interacted with Target Structure (F_1 (4,68) < 1; F_2 (4,102) < 1), nor with Prime Structure (F_1 (4,68) < 1; F_2 (4,204) < 1), nor did the three-way interaction between Block, Target Structure, and Prime Structure approach significance (F_1 (8,136) < 1; F_2 (8,204) < 1). Therefore, the data were collapsed across blocks for the subsequent analyses.

Table 1 MEAN NAMING LATENCIES (IN MS) AND PERCENTAGE OF ERRORS (IN PARENTHESES) IN EXPERIMENT 1.

	Target Structure		
Prime Structure	CV words (e.g., KANO)	CVC words (e.g., KAKTUS)	CV[C] words (e.g., KAPPER)
CV primes	455 (1.6)	461 (1.2)	461 (1.1)
CVC primes	448 (1.2)	453 (1.5)	449 (1.3)
Neutral primes	487 (2.4)	492 (2.4)	484 (1.4)
Mean	463	469	465

The main effect of Target Structure was only significant by participants but not by items (F_1 (2,34) = 8.30, MS_e = 52.06, p = .001; F_2 (2,51) < 1). Participants named CV targets fastest (463 ms) followed by CV[C] targets (465 ms) and CVC targets (469 ms). The interaction between Target Structure and Prime Structure was only significant by participants but not by items (F_1 (4,68) = 2.59, MS_e = 44.90, p = .044; F_2 (4,102) = 1.18, n.s.). As Figure 3 shows, the naming latencies were shortest after CVC primes and longest after neutral primes for all three target types.

The main effect of Prime Structure was significant (F_1 (2,34) = 93.93, MS_e = 222.77, p < .001; F_2(2,102) = 215.16, MS_e = 97.61, p < .001). Target names were produced fastest when preceded by a CVC prime (450 ms), slower when preceded by a CV prime (459 ms), and slowest when preceded by a neutral prime (488 ms). Dunnett's tests (p < .05) showed that both the CV and the CVC priming condition differed significantly from the neutral control condition. Planned comparisons showed that the 9 ms difference between the CV and the CVC priming condition was marginally significant by participants and significant by items (t_1 (34) = 1.88, MS_e = 222.77, p < .10; t_2 (102) = 2.83, MS_e = 97.61, p < .01).

In the four-choice test of prime visibility participants of Experiment 1 performed practically at chance level (28.46% correct responses).

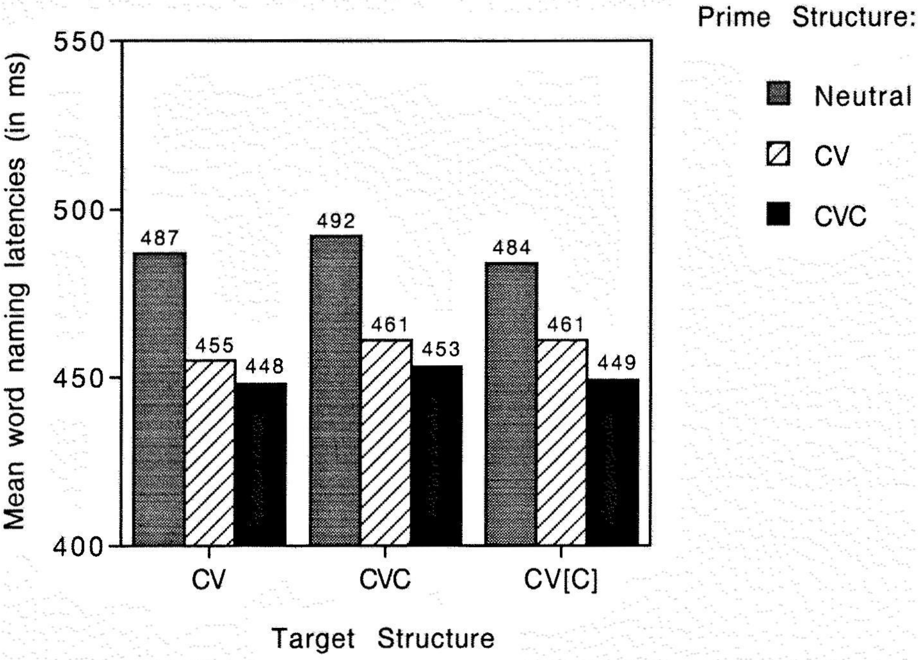

Figure 3 *Mean naming latencies in Experiment 1.*

Discussion

The data do not show any sign of a syllable match effect. Both CV and CVC primes significantly facilitated the naming of the targets. CVC primes yielded larger facilitation effects than CV primes for all three categories of target items. Thus, the size of the priming effect increased with increasing segmental overlap between prime and target. This result contradicts the syllable priming hypothesis according to which priming should only occur in the syllable match condition. The naming latencies for the CV[C] targets showed a 12 ms difference between the CV and the CVC priming condition (461 ms and 449 ms, respectively) which proved to be significant (t_1 (34) = 3.72, MS_e = 98.96, $p < .01$; t_2 (102) = 3.74, MS_e = 97.61, $p < .01$). This latter result also stands in contradiction to the syllable priming hypothesis which predicted no difference between CV and CVC primes for CV[C] targets.

The results clearly call for an alternative account. It is hypothesized here that the obtained facilitation effects are due to the segmental overlap between prime and target, and that the size of the priming effect is dependent on the amount of overlap but independent of the correspondence of the syllabic structure of prime and target. Since the magnitude of the priming effects in Experiment 1 increased with the increase in overlap between prime and target, the results are perfectly in accordance with a segmental overlap hypothesis. Experiment 2 was designed to test the same materials as in Experiment 1 using a different task, i.e., picture naming.

EXPERIMENT 2: PICTURE NAMING WITH CV, CVC, AND CV[C] TARGETS

Word naming does not necessarily involve all stages of the speech production process because printed words can be named by means of nonlexical grapheme-to-phoneme conversion rules, i.e., without accessing the whole-word representation of the target in the mental lexicon (Bajo, 1988). In contrast to word naming, it is commonly agreed upon that picture naming involves lexical access because the retrieval of a picture's name must be preceded by the activation of the concept and the lemma in order to access semantic information (Huttenlocher & Kubicek, 1983; see Glaser, 1992 for a review). Therefore, picture naming can be considered as a task involving all necessary stages for speech production. Another reason to carry out a picture naming experiment was to exclude the possibility that the priming effects obtained in the word naming task (Experiment 1) were partly due to the visual similarity between prime and target. Although prime and target were separated by a pattern mask and appeared in different case, pure visual overlap effects between prime and target are still possible in word naming (Davis & Forster, 1994; Forster & Davis, 1984), whereas they cannot occur in a picture naming experiment.

The picture naming task has been shown to be sensitive to form priming effects before. Ferrand et al. (1994) showed that the naming of a picture (e.g., *pied*) was facilitated when preceded by the masked printed picture name (identity priming) (e.g., PIED) or a pseudohomophone of its name (e.g., PIEZ), but not when preceded by a masked orthographically related nonhomophonic prime (e.g., PIEN). In a more recent study, Ferrand et al. (1996) showed that picture naming, just as word naming, was facilitated by the prior masked presentation of the picture name's first syllable as compared to a condition in which the prime was either shorter or longer than the first syllable of the picture name. However, Ferrand et al. (in press) did not include a picture naming experiment in their syllable priming study with English materials.

The aim of Experiment 2 is to test whether form priming effects in the picture naming task can be found with Dutch materials, and if so, whether the results are in accordance with the syllable priming hypothesis or rather with the segmental overlap hypothesis introduced above.

Method

Procedure. The procedure was the same as in Experiment 1 except that the target to be named was not a word but a picture. Participants first received each picture once on the computer screen to learn the "appropriate" picture names. Each picture appeared on the screen and after two seconds the "appropriate" name was added below the picture. Both remained in view for another three seconds. Participants were asked to learn the "appropriate" name for each picture. Following this learning phase, participants received two practice and three test blocks.

Materials. The targets were the same as in Experiment 1. But instead of the printed names, line drawings were presented as stimuli. The target words used in Experiment 1 had been chosen such that all targets corresponded to depictable objects. Altogether, there were 54 white-on-black line drawings of common objects, 18 for each of the three target categories, i.e., CV, CVC, and CV[C] words (see Appendix A). The pictures were drawn using Aldus Freehand 3.1, converted to Adobe Illustrator 3.2, and saved in AI format. For the presentation by means of NESU the drawings were then converted to PCX format.

The target pictures had been selected on the basis of the results obtained from two pretests. The aim of the first pretest was to determine the dominant naming responses to a set of pictures. 20 participants received printed line drawings of 91 objects and were asked to write down their names. The second pretest was designed to determine the mean response latencies for those pictures that were most consistently named in the first pretest. Another 20 participants first saw pictures of 71 objects on a computer screen. In a preview, pictures appeared individually on the screen and after two seconds the predominant picture name was added below each picture. Picture and picture name remained on the screen for another three seconds. Participants were asked to learn the association between the picture and its name. After this learning phase, only the pictures appeared on the screen again in randomized order, preceded by a fixation cross. Participants were asked to name each picture as fast as possible. Response latencies were measured by a voice key. Incorrect naming responses were excluded from the reaction time analyses. As can be seen in Table 2a, the 54 picture stimuli that were selected on the basis of the two pretests are closely matched with respect to mean frequency of occurrence, mean proportion of correct naming responses in spontaneous naming, and mean naming latencies.

Table 2a MEAN FREQUENCY OF OCCURRENCE, MEAN PROPORTION OF CORRECT NAMING RESPONSES, AND MEAN NAMING LATENCIES OF THE SELECTED PICTURE STIMULI USED IN EXPERIMENT 2.

Target Structure	Mean frequency of occurrence per one million word forms (CELEX)	Mean proportion of correct responses (pretest 1)	Mean naming latencies (pretest 2)
CV targets	16.3	70%	806 ms (SD = 194 ms)
CVC targets	17.1	72%	861 ms (SD = 238 ms)
CV[C] targets	6.0	78%	839 ms (SD = 234 ms)

The same primes were used as in Experiment 1. CV primes corresponded to the first two (e.g., ka) and CVC primes to the first three segments (e.g., kak) of a target's name (e.g., KAKTUS). Neutral primes consisted of the three characters %&$. All primes were followed by a number of hash marks such that they were identical in length with the targets.

Design. The design was the same as in Experiment 1.

Participants. 18 participants from the pool of participants of the Max Planck Institute for Psycholinguistics in Nijmegen took part in Experiment 2 in exchange for pay. None of them participated in the previous experiment. All participants were native speakers of Dutch and had normal or correct-to-normal vision.

Results

Naming latencies shorter than 350 ms and longer than 1500 ms were counted as errors (less than 1% of the data). There were 2.87% errors altogether. The mean naming latencies and error rates are summarized in Table 2 and Figure 4. An ANOVA was run with Target Structure (CV, CVC, or CV[C]), Prime Structure (CV, CVC, or neutral), and Block (1, 2, or 3) entered as main factors.

The main effect of Block was significant (F_1 (2,34) = 5.34, MS_e = 3051.26, p = .01; F_2 (2,102) = 20.87, MS_e = 787.72, $p < .001$). Target pictures were named more slowly in block 1 (683 ms) than in block 2 (666 ms) and block 3 (666 ms). However, neither the interaction between Block and Target Structure (F_1 (4,68) = 1.48, n.s.; F_2 (4,102) = 1.39, n.s.) nor the interaction between Block and Prime Structure (F_1 (4,68) < 1; F_2 (4,204) < 1), nor the three-way interaction between Block, Target Structure, and Prime Structure (F_1 (8,136) = 1.05, n.s.; F_2 (8,204) < 1) approached significance. Therefore, the data were collapsed across blocks for the subsequent analyses.

Table 2 MEAN NAMING LATENCIES (IN MS) AND PERCENTAGE OF ERRORS (IN PARENTHESES) IN EXPERIMENT 2.

	Target Structure		
Prime Structure	CV pictures (e.g., *kano*)	CVC pictures (e.g., *kaktus*)	CV[C] pictures (e.g., *kapper*)
CV primes	655 (2.9)	681 (2.6)	663 (2.4)
CVC primes	631 (2.9)	666 (3.1)	648 (2.5)
Neutral primes	691 (3.4)	713 (3.5)	697 (3.0)
Mean	659	687	669

The main effect of Target Structure was only significant by participants but not by items (F_1 (2,34) = 24.12, MS_e = 428.20, $p < .001$; F_2 (2, 51) = 2.16, n.s.). Participants named CV targets (659 ms) faster than CV[C] targets

(669 ms) and CVC targets (687 ms). Target Structure did not interact with Prime Structure (F_1 (4,68) < 1; F_2(4,102) < 1).

Most importantly, the main effect of Prime Structure was significant (F_1 (2,34) = 24.78, MS_e = 1523.98, $p < .001$; F_2(2,102) = 76.86, MS_e= 491.55, $p < .001$). The target pictures were named fastest when preceded by a CVC prime (648 ms), slower when preceded by a CV prime (667 ms), and slowest when preceded by a neutral prime (700 ms). Dunnett's tests ($p <$ .05) showed that both the CV and the CVC priming condition differed significantly from the neutral control condition. Planned comparisons showed that the 21 ms difference between the CV and the CVC priming condition was significant by items and approaching significance by participants (t_1 (34) = 1.42, MS_e = 1523.98, $p < .20$; t_2 (102) = 2.54, MS_e = 491.55, $p < .05$).

In the four-choice test of prime visibility participants of Experiment 2 performed practically at chance level (29.73% correct responses).

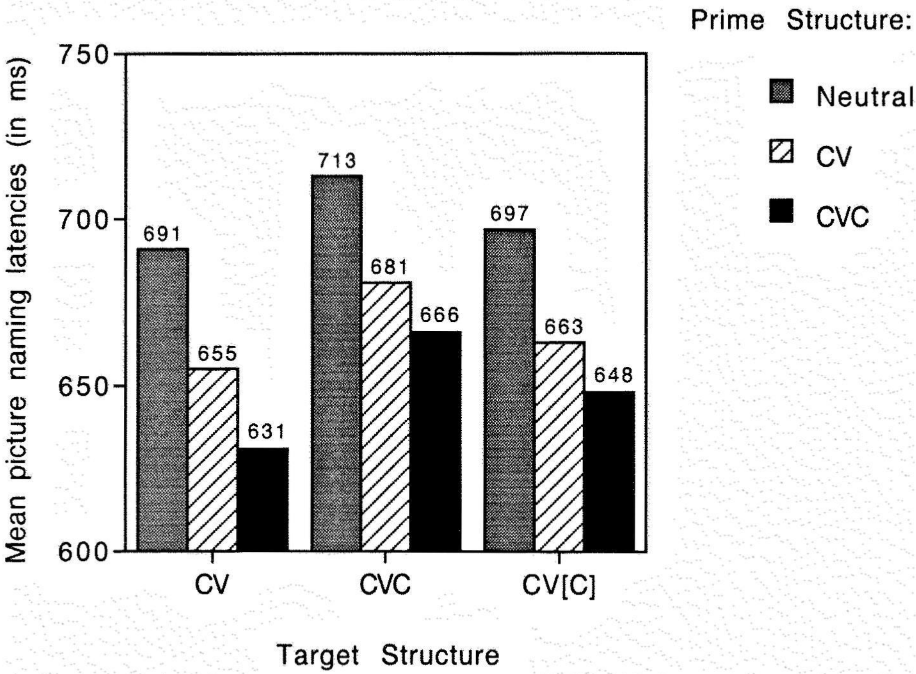

Figure 4 *Mean naming latencies in Experiment 2.*

Discussion

The pattern of results is similar to the outcome of Experiment 1, i.e., there was no sign of a syllable match effect. Both CVC and CV primes yielded facilitatory effects for all three categories of target items and CVC primes yielded stronger facilitation effects than CV primes, i.e., the size of the priming effect increased with an increase in segmental overlap between prime and target. The naming latencies for the CV[C] targets showed a difference of 15 ms between the CV and the CVC priming condition (663 ms and 648 ms, respectively) which was again significant (t_1 (34) = 2.04, $MS_e = 548.90$, $p < .05$; $t_2(102) = 2.22$, $MS_e = 491.55$, $p < .05$). These results contradict the syllable priming hypothesis but they support the segmental overlap hypothesis.

Although the results of Experiment 1 and 2 both support the segmental overlap hypothesis, they have one potential shortcoming with respect to the materials that were used. Due to other constraints on the materials (e.g., all depicted objects had to correspond to a bisyllabic, monomorphemic Dutch noun with a precisely defined phonological structure such that each item belonged to one target word category), it was not possible to find triplets of items for the three target categories that shared the first three letters. Although such triplets exist in Dutch (e.g., *fakir*, *faktor*, and *fakkel*, all of which begin with the sequence *fak*), they generally contain targets that do not correspond to depictable objects (e.g., *faktor*). This has the potential disadvantage that targets from the different categories were not preceded by the same primes. Therefore, one might argue that CV, CVC, and CV[C] targets are not comparable. Furthermore, using different primes for each target may induce additional variance in the data. Experiments 3 and 4 were designed to replicate the obtained segmental overlap effects with better controlled materials using the word naming task.

EXPERIMENT 3: WORD NAMING WITH CVC AND CV[C] TARGETS

In Experiment 3 the effect of CV and CVC primes (e.g., fa and fak) on CVC and CV[C] target words (e.g., FAKTOR and FAKKEL) was tested. CVC targets had a clear syllable boundary, whereas the syllable structure was ambiguous in CV[C] targets. The segmental overlap hypothesis predicts that both CV and CVC primes should facilitate the naming of CVC and CV[C] targets and that the priming effects should be larger in the CVC than in the CV priming condition for both types of targets.

Method

Procedure. The procedure was exactly the same as in Experiment 1. However, Experiment 3 was carried out before the other three experiments reported in this study, and a different test of prime visibility was conducted. Participants were given a two-alternatives forced choice test in which they were asked to decide whether a masked syllable prime was identical to an unmasked target syllable in upper-case or not.

Materials. The entire set of target words consisted of 84 monomorphemic bisyllabic Dutch nouns (see Appendix B). Targets could be grouped into two different subsets. Set A consisted of 21 CVC words (e.g., FAKTOR) and 21 CV[C] words (e.g., FAKKEL). The mean frequency of occurrence per one million word forms was 4.9 for the CVC and 6.6 for the CV[C] items of Set A as determined by CELEX. Items of Set A were grouped into pairs such that the first three letters of both members of a pair were identical (e.g., FAK). Set B also contained 21 CVC words and 21 CV[C] words (e.g., BINDER and BOBBEL, respectively). The mean frequency of occurrence per one million word forms was 8.3 for the CVC and 9.3 for the CV[C] items of Set B as determined by CELEX. However, items of Set B could not be grouped into pairs in the same way as items of Set A although an effort was made to maximize their segmental overlap.

There were two types of related primes either corresponding to the first two letters of a target word (CV primes) or to the first three letters of a target word (CVC primes). In the case of the Set A items, the two related primes were identical for the two members of a pair (e.g., fa and fak for FAKTOR and FAKKEL). For the Set B items, related primes were different for CVC and CV[C] words (e.g., bi and bin for BINDER vs. bo and bob for BOBBEL). Neutral primes consisted of the three characters %&$. All primes were followed by a number of hash marks such that primes and targets were always of the same length in number of characters (e.g., fa####, fak###, and %&$### for FAKTOR and FAKKEL).

Design. Experiment 3 had a between-participants design. For each target word there were three prime-target pairs, namely CV prime-target (e.g., fa#### - FAKTOR), CVC prime-target (e.g., fak### - FAKTOR), and neutral prime-target (e.g., %&$### - FAKTOR). Prime-target pairs were rotated across three groups of participants such that each participant saw each target word only once, but still received all three experimental conditions. Each participant saw 84 prime-target pairs, 28 in each condition. The 84 prime-target pairs for each of the three groups of participants were grouped into four blocks each containing 21 prime-target pairs. The order of presentation of the four blocks was counterbalanced across participants in each group. Prime-target pairs were randomized individually for each participant within each block.

Participants. 36 participants from the participant pool of the Max Planck Institute for Psycholinguistics in Nijmegen took part in Experiment 3 in exchange for pay. None of them participated in any of the earlier experiments. All participants were native speakers of Dutch and had normal or corrected-to-normal vision.

Results

Naming latencies shorter than 300 ms and longer than 1000 ms were counted as errors (less than 1% of the data). There were 2.51% errors altogether. The mean naming latencies and error rates are summarized in Table 3 and Figure 5. An ANOVA was run with Item Type (Set A or Set B), Target Structure (CVC or CV[C]), Prime Structure (CV, CVC, or neutral), and Group (1, 2, or 3) entered as main factors.

The main effect of Item Type was significant by participants but not by items (F_1 (1,33) = 21.38, MS_e = 513.63, $p < .001$; F_2 (1,82) = 1.69, n.s.). The mean naming latencies for the Set A items (530 ms) were 10 ms slower than for the Set B items (520 ms). However, neither of the two-way interactions between Item Type and Target Structure (F_1 (1,33) < 1; F_2 (1,80) < 1) and between Item Type and Prime Structure (F_1 (2,66) < 1; F_2 (2,160) < 1), nor the three-way interaction between Item Type, Target Structure, and Prime Structure (F_1 (2,66) < 1; F_2 (2,160) < 1) approached significance. Therefore, items of Set A and B were analyzed together in the subsequent analyses.

The main effect of Group (F_1 (2,33) < 1) was not significant. Therefore, data from the three groups were collapsed for the subsequent analyses.

The main effect of Target Structure (F_1 (1,35) = 3.16, n.s.; F_2 (1,82) < 1) was not significant and Target Structure did not interact with Prime Structure (F_1 (2,70) < 1; F_2(2,164) < 1).

Table 3 MEAN NAMING LATENCIES (IN MS) AND PERCENTAGE OF ERRORS (IN PARENTHESES) IN EXPERIMENT 3.

		Target Structure	
Item Type	Prime Sructure	CV[C] words (e.g., FAKKEL)	CVC words (e.g., FAKTOR)
Set A			
	CV primes (e.g., fa####)	526 (2.8)	535 (2.4)
	CVC primes (e.g., fak###)	516 (3.2)	525 (2.4)
	Neutral primes (e.g., %&$###)	542 (3.2)	545 (2.0)
	Mean	528	535
		CV[C] words (e.g., BAKKER)	CVC words (e.g., BANJO)
Set B			
	CV primes (e.g., ba#### or ba###)	515 (3.6)	521 (0.4)
	CVC primes (e.g., bak### or ban##)	509 (3.2)	512 (1.6)
	Neutral primes (e.g., %&$### or %&$##)	534 (1.6)	533 (2.8)
	Mean	519	522

The main effect of Prime Structure, however, was significant (F_1 (2,70) = 22.36, $MS_e = 388.37$, $p < .001$; F_2(2,164) = 18.80, $MS_e = 523.79$, $p < .001$). The naming latencies were shortest when targets were preceded by a CVC prime (516 ms), slightly longer when preceded by a CV prime (524 ms), and longest when preceded by a neutral prime (538 ms). Dunnett's tests ($p < .05$) showed that both the CV and the CVC priming condition differed significantly from the neutral control condition. Planned comparisons showed that the 8 ms difference between the CV and the CVC priming condition approached significance (t_1 (70) = 1.64, MS_e = 388.37, $p < .15$; t_2 (164) = 1.47, MS_e = 523.79, $p < .15$).

The test of prime visibility showed that participants correctly decided on the identity or non-identity of prime and target in 58.6% of the cases, i.e., they performed slightly above chance level (50%).

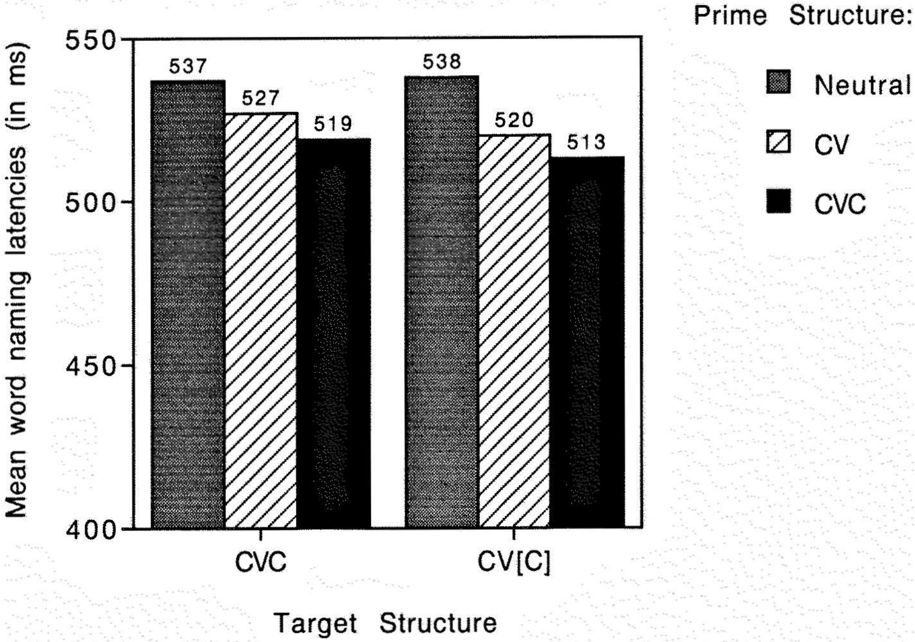

Figure 5 *Mean naming latencies in Experiment 3.*

Discussion

Both the naming latencies for CVC and CV[C] target words were shortened significantly when preceded by a CV or a CVC prime as compared to a neutral control condition. CVC primes yielded slightly larger priming effects than CV primes for both types of target words. Again, this result supports the segmental overlap hypothesis whereas it stands in contradiction to the syllable priming hypothesis according to which the naming of CVC targets should only be facilitated when preceded by a CVC prime but not when preceded by a CV prime. However, CV primes also yielded a significant facilitation effect for these targets. The naming latencies of CV[C] targets was facilitated both by CV and CVC primes and the 8 ms difference between the two priming conditions did not reach significance. However, as can be seen in Figure 5, it was again the CVC priming condition that yielded the largest facilitation effects.

The fact that the interaction between Item Type and Prime Structure did not approach significance showed that there was no difference between the priming effects for CVC and CV[C] targets that shared their initial segments and those that did not.

EXPERIMENT 4: WORD NAMING WITH CV AND CVC TARGETS

Experiment 4 tested the effect of CV and CVC primes (e.g., `de` and `del`) on CV and CVC target words (e.g., DELER and DELTA), both having unambiguous syllabification. The segmental overlap hypothesis predicts that both CV and CVC primes should yield a facilitation effect for both types of target words, no matter whether prime and target share the first syllable or not. Effects should be larger for CVC primes than for CV primes due to greater segmental overlap with the target word.

Method

Procedure. The procedure was exactly the same as in Experiment 1.

Materials. There were 84 target words (see Appendix B). All target words were monomorphemic bisyllabic Dutch nouns. Again, there were two different subsets of target words. Set A consisted of 21 CVC words beginning with a CVC syllable (e.g., FAKTOR) and 21 CV words beginning with a CV syllable (e.g., FAKIR). The mean frequency of occurrence per one million word forms was 6.2 for the CVC and for the CV items of Set A as determined by CELEX. Items of Set A were grouped into pairs such that the first three letters of both members of a pair were identical (e.g., FAK). Set B also contained 21 CVC words (e.g., PANTER) and 21 CV words (e.g., POKER). The mean frequency of occurrence per one million word forms was 9.3 for the CVC and 32.7 for the CV items of Set B as determined by CELEX. However, items of Set B could not be grouped into pairs in the same way as items of Set A.

There were two types of related primes, CV and CVC primes. For Set A items, the two related primes were identical for the two members of a pair (e.g., fa and fak for FAKTOR and FAKIR). For Set B items, related primes were different for CVC and CV target words (e.g., pa and pan for PANTER vs. po and pok for POKER). Neutral primes consisted of the three characters %&$. All primes were followed by a number of hash marks such that primes and targets were always of the same length (e.g., fa####, fak###, and %&$### for FAKTOR vs. fa###, fak##, and %&$## for FAKIR).

Design. Experiment 4 had a within-participants design. Participants received each target three times, once preceded by a CV prime (e.g., fa#### - FAKTOR), once preceded by a CVC prime (e.g., fak### - FAKTOR), and once preceded by a neutral prime (e.g., %&$### - FAKTOR). The 252 prime-target pairs were grouped into three different blocks such that half of the targets in each block came from Set A and half came from Set B. Half of the items within Set A and B were CV targets, the other half were CVC targets. Furthermore, the number of priming conditions was equally distributed among the Set A and B items within each block. Each participant received all three blocks, but the order of blocks was counterbalanced across participants. Items were randomized individually for each participant within blocks.

Participants. 24 participants from the pool of participants of the Max Planck Institute for Psycholinguistics in Nijmegen took part in Experiment 4 in exchange for pay. None of them participated in any of the earlier experiments. All participants were native speakers of Dutch and had normal or corrected-to-normal vision.

Results

Naming latencies shorter than 300 ms and longer 1000 ms were counted as errors (less than 1% of the data). There were 2.46% errors altogether. The mean naming latencies and error rates are summarized in Table 4 and Figure 6. An ANOVA was run with Item Type (Set A or Set B), Target Structure (CV or CVC), Prime Structure (CV, CVC, or neutral), and Block (1, 2, or 3) entered as main factors.

Table 4 MEAN NAMING LATENCIES (IN MS) AND PERCENTAGE OF ERRORS (IN PARENTHESES) IN EXPERIMENT 4.

Item Type	Prime Structure	Target Structure CV[C] words (e.g., DELER)	 CVC words (e.g., DELTA)
Set A			
	CV primes (e.g., de###)	485 (4.0)	497 (2.6)
	CVC primes (e.g., del##)	483 (4.6)	487 (1.8)
	Neutral primes (e.g., %&$##)	513 (4.0)	515 (2.0)
	Mean	494	500
		CV[C] words (e.g., POKER)	CVC words (e.g., PANTER)
Set B			
	CV primes (e.g., po### or pa####)	490 (1.4)	501 (1.2)
	CVC primes (e.g., pok## or pan###)	480 (2.6)	491 (1.6)
	Neutral primes (e.g., %&$## or %&$###)	505 (2.6)	513 (1.6)
	Mean	491	502

The effect of Item Type was not significant (F_1 (1,23) < 1; F_2 (1,82) < 1) and showed no interaction with any other effect. Therefore, items of Set A and B were analyzed together in the subsequent analyses.

The main effect of Block was significant (F_1 (2,46) = 37.71, MS_e = 1235.42, $p < .001$; F_2 (2,164) = 160.06, MS_e = 522.58, $p < .001$) reflecting the fact that naming latencies decreased with repetition. Target words were named slowest at the first presentation (517 ms), faster at the second presentation (491 ms), and fastest at the third presentation (482 ms). The interaction between Block and Target Structure was not significant (F_1

(2,46) = 1.15, n.s.; F_2 (2,164) < 1), but the interaction between Block and Prime Structure was significant (F_1 (4,92) = 3.03, MS_e = 308.63, p = .022; F_2 (4,328) = 2.62, MS_e = 689.61, p = .035). This interaction reflects the fact that the priming effects increased across blocks (see Table 4a).

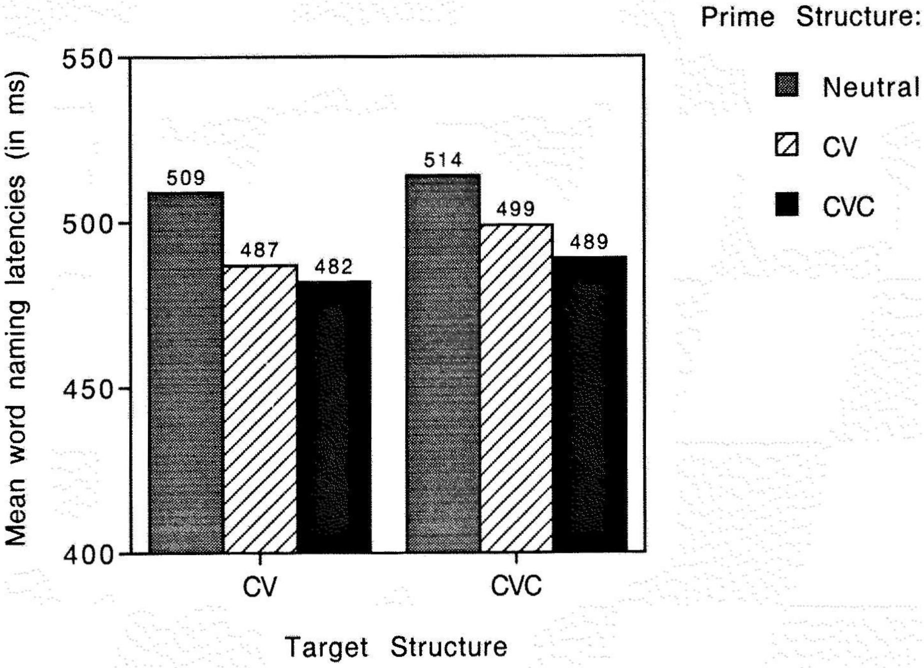

Figure 6 *Mean naming latencies in Experiment 4.*

However, the three-way interaction between Block, Target Structure, and Prime Structure did not approach significance (F_1 (4,92) = 1.86, n.s.; F_2 (4,328) < 1). Thus, with repeated production of the target words, the pattern of the priming effect remained the same. Therefore, the data were collapsed across blocks in the subsequent analyses.

The main effect of Target Structure was significant by participants and marginally significant by items (F_1 (1,23) = 31.31, MS_e = 74.53, p < .001; F_2 (1,82) = 3.21, MS_e = 1194.17, p = .077). The mean naming latencies for CV targets (493 ms) were 8 ms faster than for CVC targets (501 ms). The interaction between Target Structure and Prime Structure was only significant by participants but not by items (F_1 (2,46) = 3.35, MS_e = 43.79, p = .044; F_2 (2,164) = 1.84, n.s.). As can be seen in Figure 6, latencies were shortest after CVC primes for both types of targets.

Table 4a MEAN NAMING LATENCIES (IN MS) ACROSS REPETITIONS IN EXPERIMENT 4.

	Repetition		
Prime Structure	Block 1	Block 2	Block 3
CV	517	487	476
CVC	507	479	469
Neutral	526	508	501
Mean	517	491	482

Most importantly, the main effect of Prime Structure was significant (F_1 (2,46) = 96.60, MS_e = 90.71, $p < .001$; F_2(2,146) = 114.05, MS_e=135.96, $p < .001$). Naming latencies were shortest when targets were preceded by CVC primes (485 ms), slightly longer when preceded by CV primes (493 ms), and longest when preceded by neutral primes (512 ms). Dunnett's tests ($p < .05$) showed that both the CV and the CVC priming condition differed significantly from the neutral control condition. Planned comparisons showed that the 8 ms difference between the CV and the CVC priming condition was also significant (t_1 (46) = 2.91, MS_e = 90.71, $p < .01$; t_2 (164) = 3.15, MS_e = 135.96, $p < .01$).

In the four-choice test of prime visibility participants of Experiment 3 performed practically at chance level (28.21% correct responses).

Discussion

The results of Experiment 4 clearly support the segmental overlap hypothesis. Both CV and CVC primes yielded significant priming effects for CV and CVC targets when compared to the neutral control condition. Furthermore, the size of the facilitation effect was predicted to be dependent on the amount of segmental overlap between prime and target, i.e., the greater the overlap between prime and target, the greater the facilitation effect obtained by the prime. This prediction is also confirmed since planned comparisons showed that CVC primes yielded significantly larger facilitation effects than CV primes. Thus, the segmental overlap hypothesis can perfectly account for the outcome of Experiment 4 without making reference to the syllabic structure of prime and target.

GENERAL DISCUSSION

The results of the experiments reported in this study showed no sign of a syllable match effect in Dutch. Visually masked primes that corresponded to the first syllable of a target did not yield larger facilitation effects for any type of target words than primes that were one segment shorter or longer than the target's first syllable. In all four naming experiments, orthographically related primes that corresponded either to the first two or to the first three segments of the target yielded significant facilitation effects when compared with neutral control primes. In Experiment 1, CVC primes facilitated the naming of CV, CVC, and CV[C] target words more than CV primes, but CV primes also yielded significant facilitation for any type of target. This result contradicts the syllable priming hypothesis which predicted facilitatory effects for CV targets only when preceded by CV primes but not when preceded by CVC primes. For CVC targets facilitation effects were only predicted in the CVC but not in the CV priming condition, and for CV[C] targets both CV and CVC primes were predicted to yield similar priming effects. However, both types of related primes facilitated the naming of any target word category. Furthermore, CVC primes yielded larger priming effects than CV primes for any target type. This outcome called for an alternative account. It was suggested that the priming effects may be the result of a segmental overlap effect.

According to a segmental overlap hypothesis the magnitude of a facilitation effect yielded by a related prime increases with the increase in segmental overlap between prime and target. That is, both CV and CVC primes should facilitate the naming of any type of target but the effects should be larger in the CVC than in the CV priming condition. It is assumed that the priming effect is not dependent on the relationship between the syllabic structure of prime and target. The pattern of results obtained in Experiment 1 is compatible with the segmental overlap hypothesis.

To test whether the segmental overlap effect found in Experiment 1 could also be obtained with a different task, a picture naming experiment was carried out (Experiment 2). Since Experiments 1 and 2 used the same materials, they only differed with respect to the task. The priming effects obtained in picture naming were comparable to word naming, i.e., both tasks produced exactly the same pattern of results. The data of Experiments 1 and 2 cannot be accounted for by a syllable priming hypothesis. The fact that CV targets exhibited the same pattern of effects as the other two target categories suggested that the obtained priming effect was not the result of a syllabic overlap between prime and target but due to segmental overlap. Furthermore, under the syllable priming hypothesis there should have been no priming in the syllable mismatch condition, i.e., CV primes should have had the same effect on the naming of CVC targets as neutral primes and CVC primes should not have facilitated the naming of CV targets when compared to a neutral control condition. However, in both experiments, related primes also yielded significant facilitation effects in the syllable mismatch condition. The segmental overlap hypothesis, however, predicted facilitation effects as soon as prime and target have some overlap, even in the syllable mismatch condition. The results of Experiment 1 and 2 clearly support the segmental overlap hypothesis.

Experiments 3 and 4 replicated the segmental overlap effect with different materials using the word naming task. In Experiment 3, both CV and CVC primes facilitated the naming of CVC and CV[C] targets. Again, there was more priming with CVC primes than with CV primes for both target categories. Experiment 4 replicated this effect with CV and CVC targets. Again, neither Experiment 3 nor Experiment 4 showed any sign of a syllable priming effect.

Another important finding of this study is that target words with ambiguous syllable boundaries (e.g., *fakkel*) did not behave differently from targets with clear syllable boundaries (e.g., *fakir* or *faktor*). However, Ferrand et al. (in press) argued that CV as well as CVC primes match the first syllable of a CV[C] target and therefore naming should be facilitated in both these priming conditions. While facilitation effects were indeed obtained in both priming conditions for CV[C] targets, CVC primes yielded consistently larger effects than CV primes. For Dutch it has been argued that the first syllable of ambisyllabic words includes the intervocalic consonant (Zwitserlood et al., 1993). Under this assumption, CV[C] targets begin with a CVC syllable, i.e., according to the syllable priming hypothesis facilitation effects should only have occurred in the CVC priming condition. However, this was not the case, since CV primes also yielded significant priming effects for both types of target words. That means, it does not play a role for the segmental priming effect whether a segment has a clear syllable affiliation or whether it is ambisyllabic. What counts is the serial position of a segment within a target word. Since the serial position for /k/ is the same in *fakir*, *faktor*, and *fakkel*, all three targets show the same pattern of priming effects when preceded by the CVC prime *fak*.

The fact that the magnitude of the facilitation effects obtained in all four Experiments increased with the increase in segmental overlap between prime and target agrees with Baumann's (1995) results. She had her participants produce encliticized verb forms upon the presentation of a visual prompt while interfering stimuli were presented auditorily. Her target utterances were bisyllabic and either began with a CV or with a CVC syllable. With respect to phonological structure her targets were comparable to the CV and CVC targets used in this study. The interfering stimuli in Baumann's study were monosyllabic and can be compared to the syllable primes used here. Baumann did not find a syllable match effect. Instead, she consistently obtained facilitation with both CV and CVC phonologically related interfering stimuli when compared to a pink noise control condition. In general, interfering stimuli yielded larger facilitation effects for both CV and CVC target utterances when they had CVC structure than when they had CV structure. The same result was found in the present study with different materials and a different experimental paradigm that had the advantage of minimizing strategic effects in the data.

The results presented here are in accordance with earlier experimental evidence showing that the phonological encoding of a word proceeds from left to right (Meyer, 1990, 1991; Meyer & Schriefers, 1991; Tousman & Inhoff, 1992). If the masked priming paradigm taps into phonological encoding one should expect a facilitatory effect in the naming task when, for instance, CVC target words are preceded by visually masked CV primes. CVC primes provide information about an additional segment and should therefore yield an additional effect. This prediction was confirmed by the data presented here. Similarly, the results of another masked priming study can be interpreted as support for the hypothesis that phonological encoding proceeds from left to right. Forster and Davis (1991) showed that targets are named more slowly when preceded by a nonhomophonic orthographically unrelated prime (e.g., take - PEAR) than when prime and target shared the same onset (pole - PEAR). Because naming latencies in the onset-sharing condition were also significantly shorter than in a rhyming condition (nair - PEAR), Forster and Davis (1991) argued that the onset effect is independent of the overall phonetic similarity between prime and target. Taken together, the results from Forster and Davis' (1991) study and from the present study suggest that the masked priming paradigm taps into the process of phonological encoding.

Although the results obtained in this study are in line with other data found with Dutch materials (Baumann, 1995), they are at variance with the results from a recent study by Ferrand et al. (1996) reporting a syllable priming effect in French. Possibly this has to do with the fact that French and Dutch differ in phonological structure. French is traditionally considered to be a syllable-timed language, whereas Dutch is stress-timed. With French materials clear syllabic effects have been obtained in perception (Mehler et al., 1981; Pallier et al., 1993), whereas in Dutch the syllable is not used as a functional unit in speech perception (Cutler, in press).

The WEAVER model of speech production provides an account for the effect found in Dutch. WEAVER (Word-form Encoding by Activation and VERification) is a spreading-activation based computer network model developed by Roelofs (1996). It is based on Levelt's (1989, 1992) model of speech production. Here, I will concentrate on the word form encoding part of WEAVER. In accordance with Levelt and Wheeldon (1994), WEAVER assumes that the syllabification of a word is computed on-line during the speech production process. This is in contrast to models which assume that the syllabification of a word form is stored in the lexicon (see, e.g., Dell, 1986, 1988). In the WEAVER model segments are not specified for syllable positions but only for their serial position in a morpheme. Links specify the *possible* syllable positions of the segments, e.g., an /n/ may occur in the coda of a preceding syllable or in the onset of a following syllable. The actual syllable positions are determined by a syllabification process. During syllabification, segmental and metrical structures that have been selected by the phonological encoder are associated. Individual segments are assigned to the syllable nodes within the metrical frame in accordance with the syllabification rules of the language. The resulting syllables provide the basis for the retrieval of articulatory motor programs from a mental syllabary, a process that is carried out by the phonetic encoder.

It is important to note that in WEAVER, segments are not specified for syllable positions but only for their serial position within a word. In particular, a C_1VC_2 prime activates all syllables in the mental syllabary containing any of the elements C_1, C_2, and V; this includes *both* the syllable C_1V and the syllable C_1VC_2. Therefore, the model does not predict a syllable match effect in Dutch speech production. In contrast, WEAVER predicts a segmental overlap effect because the masked syllable primes preactivate segments that are not specified for syllable position, i.e., only the segmental but not the syllabic structure of the target word could be primed. In computer simulations with CV and CVC target words and monosyllabic CV and CVC primes that were phonologically related to the beginning of the targets Roelofs (personal communication) obtained facilitation effects for both types of targets. However, CVC primes yielded more facilitation than CV primes for both CV and CVC targets, i.e., a segmental overlap effect was obtained but no syllable match effect. That is, the results of the computer simulations agree with the data obtained in the experiments reported in this paper.

As opposed to Dutch, French has a simpler syllable structure with relatively clear boundaries between the syllables of a word. If it is assumed that French segments are marked for syllable position in the input lexicon, as suggested by the perception studies in French, the syllable match effect in French can be accounted for by WEAVER without changing the assumptions about production in the model for French. The segments occurring in the French visually masked primes already contain information about their syllable positions. This perception information agrees with the syllable positions that are computed on-line for the segments in production and results in a syllable match effect. From this account it also becomes clear that the syllable match effect in French does not interact with a segmental overlap effect. *pal* does not prime *pa.lace* because the /l/ in *pal* is specified for the coda position whereas the /l/ in *pa.lace* occurs in onset position, i.e., there is a positional mismatch which results in the failure of CVC primes to yield a syllable priming effect for CV targets in French. Similarly, the failure to obtain a syllable priming effect in Dutch speech production can then be interpreted as a consequence of the absence of syllable information by perception.

However, the results obtained by Ferrand et al. (in press) with English materials contradict this account. Although English is similar to Dutch with respect to syllable structure, Ferrand et al. (in press) report a syllable priming effect for English speech production. Thus, there is a discrepancy between the results obtained in speech perception (Cutler et al., 1986) and production (Ferrand et al., in press) with respect to the role of the syllable in English. Furthermore, the syllable priming results for English are at variance with the Dutch results reported here. One possible explanation for this may lie in the different prime exposure durations used in this study (50 ms) and in the Ferrand et al. (in press) study (29 ms) and the correlated differences in prime processing.

In spite of the fact that Ferrand et al. (1996, in press) obtained relatively large facilitation effects with extremely short prime exposure durations (29 ms), we did not obtain the same size of effects with a comparable prime exposure duration in our laboratory. In a pilot experiment the naming latencies of CVC target words preceded by CVC and neutral primes were compared using a prime exposure duration of 33 ms. CVC primes yielded a small but significant facilitation effect of 8 ms as compared to the neutral priming condition. However, using the same prime exposure duration with CVC and CV[C] targets preceded by CV, CVC, and neutral primes yielded no differences in the naming latencies between the three conditions. This null effect might have been due to the fact that the prime exposure duration was too short for participants to extract enough information from the primes. When the prime exposure duration was increased to 50 ms, CVC primes yielded a significant 19 msec facilitation effect for CVC targets as compared to the neutral control condition. Participants still reported not to have been aware of the presence of a prime and tests of prime visibility showed they performed at chance level when they were asked to judge the identity/non-identity between a masked prime and a target syllable of equal length. Therefore, a prime exposure duration of 50 ms was chosen for the four experiments reported in the present study.

A peculiarity of the Ferrand et al. (1996, in press) studies is that they interpreted their syllable priming effect as an orthographic effect. They argued that the syllable prime activated sublexical orthographic units that subsequently sent their activation to syllabic output units. That is, the syllable priming interpretation strongly depends on the assumption of a direct connection between orthographic input units and articulatory output units that are syllabically structured. Thus, within Ferrand et al.'s (1996, in press) framework one may argue that the difference in results was due to the difference in prime exposure duration: With an exposure duration of only 29 ms only early activation of motor programs by orthographic information was tested. By contrast, when primes were presented for 50 ms, additional phonological processes were tapped, and this may explain the difference between the English and the Dutch results. However, it is known that phonological effects emerge automatically at very early stages in the processing of printed stimuli (Ferrand & Grainger, 1992, 1993, 1994; van Orden, 1987; Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 1991; Rayner, Sereno, Lesch, & Pollatsek, 1995; see Berent & Perfetti, 1995 for a recent review). Since orthographic and phonological relatedness between syllable primes and word targets was confounded in the Ferrand et al. (1996, in press) studies as well as in this study, no clear statement can be made about the nature of the priming effect.

A problem that arises when the syllable priming effect is interpreted as an orthographic priming effect has to do with the direct mapping of activation from sublexical orthographic units to syllabic output units, at least with respect to the English data reported in Ferrand et al. (in press). English is known to have a relatively "deep" orthography (Perfetti & Bell, 1991), i.e., the mapping of graphemic information onto phonological information is less direct than in Dutch which has a relatively "shallow" orthography. The pronunciation of syllables in English often depends on the context in which they occur, i.e., many syllables have inconsistent pronunciations. The syllable *de*, for instance, is pronounced as [de] in *debit*, as [di] in *decent*, and as [dɛɪ] in *debut*. Syllables occurring in inconsistent words are called *regular inconsistent* when they are pronounced as in isolation, i.e., in accordance with the general grapheme-to-phoneme conversion rules, and *exceptional* when they were pronounced differently than in isolation (Jared & Seidenberg, 1990). Jared and Seidenberg (1990) showed that inconsistent spelling-sound correspondences affect the naming of polysyllabic (low-frequency) words. The inspection of the experimental materials used in the Ferrand et al. (in press) study shows that many of their syllable primes have inconsistent pronunciations. To give an example, the syllable *bal* which was a CVC prime in their first experiment both for the target *balcony* /bæl.kəni/ and for the target *balance* /bæ[l]əns/ can be pronounced as /bæl/ (e.g., in the two target words), but also as /bɔl/ (e.g., in *balding* /bɔl.dɪŋ/), /bɛɪl/ (e.g., in *baleful* /bɛɪl.fʊl/), /bəl/ (e.g., in *balloon* /bə.lun/), /bɑ/ (e.g., in *balmy*

/bɑ.mi/), or /bɒl/ (e.g., in *balsa* /bɒl.sə/). Assuming that activation from sublexical orthographic units is directly mapped onto syllabic output units, the question arises how the speech production system knows that the activation from <b>, <a>, <l> has to be mapped onto /bæl/ and not onto any of the other possible pronunciations for *bal.* Ferrand et al. (in press) did not discuss this issue and it is not clear how their network model could account for this point.

To summarize, there are arguments that make the interpretation of the syllable priming effect as an orthographic effect in English given by Ferrand et al. (in press) appear doubtful. It is suggested here that the priming effect in the Ferrand et al. (1996, in press) studies and in the present study are not orthographic but phonological in nature. The visually masked primes first activate orthographic units, but these do not send activation directly to articulatory output units. Instead, they activate sublexical phonological units which correspond to segments. In the case of French, these segments are specified for syllable position during perception and the production system can make use of this additional information, which results in a syllable match effect. In the case of Dutch, however, only the phonological segments but not their syllable position become preactivated when the prime is being processed. Hence, there is no syllable match but a segmental overlap effect in Dutch. The question why Ferrand et al. (in press) reported a syllable priming effect for English remains unanswered. On theoretical grounds English would have been expected to behave similarly to Dutch.

CONCLUSION

The results of the masked priming experiments reported in this study showed that there is no syllable priming effect in Dutch speech production. However, orthographically and phonologically related syllable primes facilitated the naming of word and picture targets significantly. The fact that the priming effect increased with an increase in segmental overlap between prime and target and was independent of the syllabic structure of the target word is accounted for by a segmental overlap effect. It is suggested that the effect is due to the preactivation of sublexical phonological units. The WEAVER model of speech production (Roelofs, 1996) predicted such a segmental overlap effect.

REFERENCES

BAGEMIHL, B. (1995). Language games and related areas. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 697-712). Cambridge: Blackwell.

BAJO, M.-T. (1988). Semantic facilitation with pictures and words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **14**, 579-589.

BAUMANN, M. (1995). *The production of syllables in connected speech.* Unpublished dissertation, Nijmegen University.

BERG, T. (1988). *Die Abbildung des Sprachproduktionsprozesses in einem Aktivationsflußmodell: Untersuchungen an deutschen und englischen Versprechern* [The representation of the speech production process in a spreading activation model: Studies of German and English speech errors]. Tübingen: Niemeyer.

BERENT, I. & PERFETTI, C. A. (1995). A rose is a REEZ: The two-cycles model of phonology assembly in reading English. *Psychological Review*, **102**, 146-184.

BOOIJ, G. (1995). *The phonology of Dutch.* Oxford: Clarendon Press.

BRADLEY, D. C., SÁNCHEZ-CASAS, R. M., & GARCÍA-ALBEA, J. E. (1993). The status of the syllable in the perception of Spanish and English. *Language and Cognitive Processes*, **8**, 197-233.

BROWN, A. S. (1991). A review of the tip-of-the-tongue experience. *Psychological Bulletin*, **109**, 204-223.

BROWN, C. M. & HAGOORT, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Neuroscience*, **5**, 34-44.

BURKE, D., MACKAY, D. G., WORTHLEY, J. S., & WADE, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, **30**, 237-246.

BRUCK, M., TREIMAN, R., & CARAVOLAS, M. (1995). Role of the syllable in the processing of spoken English: Evidence from a nonword comparison task. *Journal of Experimental Psychology: Human Perception and Performance*, **21**, 469-479.

COWAN, N., LEAVITT, L. A., MASSARO, D. W., & KENT, R. D. (1982). A fluent backward talker. *Journal of Speech and Hearing Research*, **25**, 48-53.

COWAN, N., BRAINE, M. D. S., & LEAVITT, L. A. (1985). The phonological and metaphonological representation of speech: Evidence from fluent backward talkers. *Journal of Memory and Language*, **24**, 679-698.

CROMPTON, A. (1981). Syllables and segments in speech production. *Linguistics*, **19**, 663-716.

CUTLER, A. (in press). The syllable's role in the segmentation of stress languages. To appear in *Language and Cognitive Processes* (Special issue, The Sperlonga Meeting III).

CUTLER, A., MEHLER, J., NORRIS, D. G., & SEGUI, J. (1986). The syllable's differing role in the segmentation of French and English. *Journal of Memory and Language*, **25**, 385-400.

DAVIS, C. & FORSTER, K. I. (1994). Masked orthographic priming: The effect of prime-target legibility. *The Quarterly Journal of Experimental Psychology*, **47A**, 673-697.

DELL, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, **93**, 283-321.

DELL, G. S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language*, **27**, 124-142.

DUPOUX, E. (1993). The time course of prelexical processing: The syllabic hypothesis revisited. In G. T. M. Altmann & R. Shillcock (Eds.), *Cognitive models of speech processing: The second Sperlonga meeting* (pp. 81-114). Hillsdale, NJ: Lawrence Erlbaum.

FALLOWS, D. (1981). Experimental evidence for English syllabification and syllable structure. *Journal of Linguistics*, **17**, 309-317.

FERRAND, L. & GRAINGER, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *Quarterly Journal of Experimental Psychology*, **45A**, 353-372.

FERRAND, L. & GRAINGER, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, **31**, 119-122.

FERRAND, L. & GRAINGER, J. (1994). Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology*, **47A**, 365-382.

FERRAND, L., GRAINGER, J., & SEGUI, J. (1994). A study of masked form priming in picture and word naming. *Memory & Cognition*, **22**, 431-441.

FERRAND, L., SEGUI, J., & GRAINGER, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, **35**, 708-723.

FERRAND, L., SEGUI, J., & HUMPHREYS, G. W. (in press). The syllable's role in word naming. *Memory & Cognition.*

FORSTER, K. I. (1987). Form-priming with masked primes: The best match hypothesis. In M. Coltheart (Ed.), *Attention and Performance XII. The psychology of reading* (pp. 127-146). Hillsdale, NJ: Erlbaum.

FORSTER, K. I. (1993). Form-priming and temporal integration in word recognition. In G. T. M. Altmann & R. Shillcock (Eds.), *Cognitive models of speech processing: The second Sperlonga meeting* (pp. 467-495). Hillsdale, NJ: Lawrence Erlbaum.

FORSTER, K. I. & CHAMBERS, S. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior*, **12**, 627-635.

FORSTER, K. I. & DAVIS, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **10**, 680-698.

FORSTER, K. I. & DAVIS, C. (1991). The density constraint on form-priming in the naming task: Interference effects from a masked prime. *Journal of Memory and Language*, **30**, 1-25.

FORSTER, K. I., DAVIS, C., SCHOKNECHT, C., & CARTER, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *The Quarterly Journal of Experimental Psychology*, **39A**, 211-251.

FOWLER, C. A., TREIMAN, R., & GROSS, J. (1993). The structure of English syllables and polysyllables. *Journal of Memory and Language*, **32**, 115-140.

FREDERIKSEN, J. R., & KROLL, J. F. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception and Performance*, **2**, 361-379.

GILLIS, S. & DE SCHUTTER, G. (1996). Intuitive syllabification: universals and language specific constraints. *Journal of Child Language*, **23**, 487-514.

GLASER, W. R. (1992). Picture naming. *Cognition*, **42**, 61-105.

GRAINGER, J. & FERRAND, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language*, **35**, 623-647.

HOMBERT, J.-M. (1986). Word games: Some implications for analysis of tone and other phonological constructs. In J. J. Ohala & J. J. Jaeger (Eds.), *Experimental phonology* (pp. 175-186). Orlando: Academic Press.

HUMPHREYS, G. W., EVETT, L. J., QUINLAN, P. T., & BESNER, D. (1987). Orthographic priming: Qualitative differences between priming from identified and unidentified primes. In M. Coltheart (Ed.), *Attention and Performance XII. The psychology of reading* (pp. 105-125). Hillsdale, NJ: Erlbaum.

HUTTENLOCHER, J., & KUBICEK, L. F. (1983). The source of relatedness effects on naming latency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **9**, 486-496.

ITÔ, J. (1989). A prosodic theory of epenthesis. *Natural Language and Linguistic Theory*, **7**, 217-259.

JARED, D. & SEIDENBERG, M. S. (1990). Naming multisyllabic words. *Journal of Experimental Psychology: Human Perception and Performance*, **16**, 92-105.

KAHN, D. (1976). *Syllable-based generalizations in English phonology*. Ph. D. dissertation. New York: Garland, 1980.

KEARNS, R., FRAUENFELDER, U., & CONTENT, A. (in preparation). French syllabification - some experimental evidence.

KLAPP, S. T., ANDERSON, W. G., & BERRIAN, R. W. (1973). Implicit speech in reading reconsidered. *Journal of Experimental Psychology*, **100**, 368-374.

LEFKOWITZ, N. (1991). *Talking backwards, looking forwards. The French language game Verlan.* Tübingen: Narr.

LEVELT, W. J. M. (1989). *Speaking. From intention to articulation.* Cambridge, MA: MIT Press.

LEVELT, W. J. M. (1992). Accessing words in speech production: Stages, processes and representations. *Cognition*, **42**, 1-22.

LEVELT, W. J. M. (1993). Timing in speech production with special reference to word form encoding. *Annals of the New York Academy of Sciences*, **682**, 283-295.

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

LOVELACE, E. (1987). Attributes that come to mind in the TOT state. *Bulletin of the Psychonomic Society*, **25**, 370-372.

MACKAY, D. G. (1970). Spoonerisms: The structure of errors in the serial order of speech. *Neuropsychologia*, **8**, 323-350.

MCQUEEN, J. M. (submitted). Segmentation of continuous speech using phonotactics.

MEHLER, J., DOMMERGUES, J. Y., FRAUENFELDER, U., & SEGUI, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior*, **20**, 298-305.

MEYER, A. S. (1990). The time course of phonological encoding in language production: The encoding of successive syllables of a word. *Journal of Memory and Language*, **29**, 524-545.

MEYER, A. S. (1991). The time course of phonological encoding in language production: Phonological encoding inside a syllable. *Journal of Memory and Language*, **30**, 69-89.

MEYER, A. S. (1992). Investigation of phonological encoding through speech error analyses: Achievements, limitations, and alternatives. *Cognition*, **42**, 181-211.

MEYER, A. S. & SCHRIEFERS, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **17**, 1146-1160.

MORAIS, J., CONTENT, A., CARY, L., MEHLER, J., & SEGUI, J. (1989). Syllabic segmentation and literacy. *Language and Cognitive Processes*, **4**, 57-67.

NOOTEBOOM, S. (1969). The tongue slips into patterns. In A. G. Sciarone, A. J. von Essen, & A. A. van Raad (Eds.), *Nomen: Leyden studies in linguistics and phonetics* (pp. 114-132). The Hague: Mouton.

NORRIS, D., MCQUEEN, J. M., CUTLER, A., & BUTTERFIELD, S. (submitted). The possible-word constraint in the segmentation of continuous speech.

NUSBAUM, H. & DEGROOT, J. (1990). The role of syllables in speech perception. In M. Ziolkowski, M. Noske, & K. Deaton (Eds.), *Papers from the 26th Regional Meeting of the Chicago Linguistic Society. Volume 2: The parasession on the syllable in phonetics & phonology* (pp. 287-317). Chicago: Chicago Linguistic Society.

VAN ORDEN, G. C. (1987). A ROWS is a ROSE: Spelling, sound, and reading. *Memory & Cognition*, **15**, 181-198.

PALLIER, C., SEBASTIÁN-GALLÈS, N., FELGUERA, T., CHRISTOPHE, A., & MEHLER, J. (1993). Attentional allocation within the syllabic structure of spoken words. *Journal of Memory and Language*, **32**, 373-389.

PERFETTI, C. A., BELL, L. C., & DELANEY, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking. *Journal of Memory and Language*, **27**, 59-70.

PERFETTI, C. A. & BELL, L. C. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory and Language*, **30**, 473-485.

RAYNER, K., SERENO, S. C., LESCH, M. F., & POLLATSEK, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science*, **6**, 26-32.

ROELOFS, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, **35**, 854-876.

SCHILLER, N. O., MEYER, A. S., BAAYEN, R. H., & LEVELT, W. J. M. (1996). A comparison of lexeme and speech syllables in Dutch. *Journal of Quantitative Linguistics*, **3**, 8-28.

SCHILLER, N. O., MEYER, A. S., & LEVELT, W. J. M. (1997). The syllabic structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, **40**, 103-140.

SEBASTIÁN-GALLÈS, N., DUPOUX, E., SEGUI, J., & MEHLER, J. (1992). Contrasting syllabic effects in Catalan and Spanish. *Journal of Memory and Language*, **31**, 18-32.

SEGUI, J., DUPOUX, E., & MEHLER, J. (1990). The role of the syllable in speech segmentation, phoneme identification, and lexical access. In G. Altmann (Ed.), *Cognitive models of speech processing. Psycholinguistic and computational perspectives* (pp. 263-280). Cambridge, MA: MIT Press.

SELKIRK, E. O. (1984). On the major class features and syllabic theory. In M. Aronoff & R. T. Oehrle (Eds.), *Language sound structure. Studies in phonology presented to Morris Halle by his teacher and students* (pp. 107-136). Cambridge: MIT Press.

SHATTUCK-HUFNAGEL, S. (1979). Speech errors as evidence for a serial ordering mechanism in sentence production. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing* (pp. 295-342). New York: Halsted Press.

SHATTUCK-HUFNAGEL, S. (1987). The role of word onset consonants in speech production planning: New evidence from speech error patterns. In E. Keller & M. Gopnik (Eds.), *Motor and sensory processing in language* (pp. 17-51). Hillsdale, NJ: Erlbaum.

SHATTUCK-HUFNAGEL, S. (1992). The role of word structure in segmental serial ordering. *Cognition*, **42**, 213-259.

STEMBERGER, J. P. (1982). The nature of segments in the lexicon: Evidence from speech errors. *Lingua*, **56**, 235-259.

TOUSMAN, S. & INHOFF, A. (1992). Phonology in multisyllabic word recognition. *Journal of Psycholinguistic Research*, **21**, 525-544.

TREIMAN, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, **15**, 49-74.

TREIMAN, R. (1986). The division between onsets and rimes in English syllables. *Journal of Memory and Language*, **25**, 476-491.

TREIMAN, R. & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

TREIMAN, R., FOWLER, C. A., GROSS, J., BERCH, D., & WEATHERSTON, S. (1995). Syllable structure or word structure? Evidence for onset and rime units with disyllabic and trisyllabic stimuli. *Journal of Memory and Language*, **34**, 132-155.

TREIMAN, R. & ZUKOWSKI, A. (1990). Toward an understanding of English syllabification. *Journal of Memory and Language*, **29**, 66-85.

TREIMAN, R. & ZUKOWSKI, A. (1996). Children's sensitivity to syllables, onsets, rimes, and phonemes. *Journal of Experimental Child Psychology*, **61**, 193-215.

VAN TURENNOUT, M., HAGOORT, P., & BROWN, C. M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **23**, 787-806.

VROOMEN, J. & DE GELDER, B. (1994). Speech segmentation in Dutch: No role for the syllable. In *Proceedings of the 1994 International Conference on Spoken Language Processing, September 18-22, 1994, Yokohama* (pp. 1135-1138).

WHEELDON, L. & LEVELT, W. J. M. (1995). Monitoring the time course of phonological encoding. *Journal of Memory and Language*, **34**, 311-334.

ZWITSERLOOD, P., SCHRIEFERS, H., LAHIRI, A., & VAN DONSELAAR, W. (1993). The role of syllables in the perception of spoken Dutch. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **19**, 260-271.

APPENDICES

Appendix A STIMULUS MATERIALS IN EXPERIMENTS 1 AND 2.

Target Structure		
CV targets	CVC targets	CV[C] targets
ketel ('kettle')	borstel ('brush')	visser ('fisherman')
degen ('sword')	wortel ('carrot')	ridder ('knight')
lama ('llama')	hamster ('id.')	passer ('compass')
jager ('hunter')	lifter ('hitchhiker')	mossel ('mussel')
motor ('motorbike')	cirkel ('circle')	lasso ('id.')
roker ('smoker')	pinda ('peanut')	kussen ('pillow')
toren ('tower')	kaktus ('cactus')	ketting ('chain')
vogel ('bird')	masker ('mask')	kapper ('hairdresser')
foto ('photograph')	filter ('id.')	wekker ('alarm clock')
beker ('mup')	zuster ('sister')	tunnel ('id.')
kegel ('cone')	dokter ('docter')	tekkel ('dachshund')
sofa ('id.')	herder ('shepherd')	sikkel ('sickle')
koning ('king')	halter ('dumb-bell')	puzzel ('id.')
kano ('canoe')	varken ('pig')	monnik ('monk')
robot ('id.')	bunker ('id.')	mammoet ('mammoth')
bezem ('broom')	panty ('tights')	ladder ('id.')
tuba ('id.')	tempel ('temple')	kassa ('cash register')
zadel ('saddle')	bumper ('id.')	fakkel ('torch')

Appendix B STIMULUS MATERIALS IN EXPERIMENT 3 (SET A).

Target Structure	
CV[C] words	CVC words
ballast ('id.')	balsem ('balsam')
borrel ('drink')	borstel ('brush')
fakkel ('torch')	faktor ('factor')
hennep ('hemp')	hendel ('trade')
herrie ('noise')	herder ('shepherd')
Holland ('id.')	holster ('id.')
horror ('id.')	horzel ('hornet')
kaffer ('boor')	kaftan ('caftan')
kerrie ('curry')	kermis ('fairground')
ketting ('chain')	ketjap ('soya sauce')
kikker ('frog')	kikvors ('frog')
korrel ('grain')	korpus ('corpus')
lasso ('id.')	laster ('slander')
lekkers ('sweet')	lektor ('lecturer')
linnen ('linen')	linde ('lime tree')
manna ('id.')	mantel ('coat')
monnik ('monk')	monster ('id.')
pellen ('peel')	pelgrim ('pilgrim')
penning ('penny')	pendel ('hanging lamp')
pollen ('id.')	polka ('id.')
tennis ('id.')	tensie ('pressure')

STIMULUS MATERIALS IN EXPERIMENT 3 (SET B).

Target Structure	
CV[C] words	CVC words
bakker ('baker')	banjo ('id.')
bobbel ('bubble')	binder ('id.')
buffel ('buffalo')	filter ('id.')
hobby ('id.')	herberg ('inn')
hommel ('drone')	hertog ('duke')
kapper ('hairdresser')	kaktus ('cactus')
kassa ('cash register')	kelder ('cellar')
kennel ('id.')	kapsel ('hair-style')
koffie ('coffee')	kaste ('caste')
koppel ('couple')	kolder ('nonsense')
letter ('id.')	letsel ('injury')
lotto ('lottery')	wimpel ('pennant')
makker ('pal')	marmer ('marble')
mokka ('mocha')	mentor ('tutor')
peddel ('paddle')	polder ('id.')
rabbi ('id.')	porto ('postage')
rommel ('lumber')	pinda ('peanut')
teller ('counter')	handel ('trade')
toffee ('id.')	tempel ('temple')
tunnel ('id.')	kansel ('pulpit')
wekker ('alarm clock')	wortel ('carrot')

Appendix C STIMULUS MATERIALS IN EXPERIMENT 4 (SET A).

Target Structure	
CV words	CVC words
balie ('counter')	balsem ('balsam')
bonus ('id.')	bonsai ('id.')
deken ('blanket')	deksel ('lid')
deler ('divisor')	delta ('id.')
donor ('id.')	donder ('thunder')
fakir ('id.')	faktor ('factor')
hamer ('hammer')	hamster (id.')
harem ('id.')	harnas ('armour')
heler ('receiver')	helper ('id.')
honing ('honey')	honderd ('hundred')
kano ('canoe')	kansel ('pulpit')
kaper ('hijacker')	kapsel ('hair-style')
kerel ('fellow')	kermis ('fairground')
ketel ('kettle')	ketjap ('soja sauce')
kilo ('id.')	kilte ('chilliness')
kola ('id.')	kolder ('nonsense')
koren ('corn')	korpus ('corpus')
lening ('loan')	lente ('spring')
maning ('dun')	mantel ('coat')
merel ('blackbird')	mergel ('marl')
polo ('id.')	polder ('id.')

STIMULUS MATERIALS IN EXPERIMENT 4 (SET B).

Target Structure	
CV words	CVC words
forum ('id.')	filter ('id.')
foto ('photograph')	firma ('firm')
kader ('framework')	kelder ('cellar')
motor ('motorbike')	mensa ('refectory')
visie ('vision')	wodka ('vodka')
basis ('id.')	marmer ('marble')
tepel ('nipple')	tosti ('toasted sandwich')
dosis ('dose')	kaktus ('cactus')
ruzie ('row')	rosbief ('roast beef')
bodem ('bottom')	moslim ('Muslim')
poker ('id.')	panter ('panther')
boter ('butter')	kosmos ('cosmos')
fabel ('fable')	wortel ('carrot')
lepel ('spoon')	mentor ('tutor')
liter ('litre')	pinda ('peanut')
tafel ('desk')	tempo ('id.')
sofa ('id.')	zombie ('id.')
bezem ('broom')	binder ('id.')
divan ('id.')	handel ('trade')
beker ('mug')	tempel ('temple')
laken ('sheet')	lakmoes ('litmus')

DOES THE SYLLABLE AFFILIATION OF INTERVOCALIC CONSONANTS HAVE AN ARTICULATORY BASIS? EVIDENCE FROM ELECTROMAGNETIC MIDSAGITTAL ARTICULOGRAPHY

CHAPTER 5

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ABSTRACT

This study investigates the articulatory timing of intervocalic consonants differing in syllable affiliation. Articulatory gestures were studied by means of electromagnetic midsagittal articulography (EMMA). If the syllable is an articulatory output unit, the stability of the articulatory timing should be a function of a segment's syllable affiliation. According to the *syllable timing hypothesis* the articulatory timing of segments should be more stable within a syllable than between syllables. The stability of the articulatory timing of the intervocalic consonants was expressed by the standard deviation of the temporal distance between two anchor points, C_1 and C_2. C_1 is defined as the release of the constriction gesture forming the word-initial consonant, and C_2 is the consonantal center of the first postvocalic consonant. This postvocalic consonant either formed the onset of the second syllable, as is the case for /k/ in *fa-kir*, or the coda of the first syllable as, e.g., in *fak-tor*, or it was ambisyllabic as, e.g., in *fak-kel*. Comparisons of the stability of articulatory timing of intervocalic consonants revealed no statistically reliable differences between the three item categories. This result offers no support for the syllable timing hypothesis.

INTRODUCTION

Syllables may play an important role in speech production and perception, at least in some languages. Metalinguistic studies have shown that speakers can make use of syllabic units at various levels of processing (see Treiman, 1983; Treiman & Danis, 1988 for English; Schiller, Meyer, & Levelt, 1997 for Dutch). However, there is very little evidence showing that syllables are used as processing units in speech production. Levelt and Wheeldon (1994) obtained a syllable frequency effect in the production of bisyllabic Dutch nouns, which was independent of word frequency. This result suggested that syllables are stored independently from words which led to the hypothesis of a *mental syllabary*, i.e., a store for precompiled articulatory motor programs of syllabic size. However, syllable frequency was correlated with segment frequency in some of Levelt and Wheeldon's experiments. When this confound was controlled for, neither a syllable nor a segment frequency effect were obtained (Levelt, Roelofs, & Meyer, accepted). This result, however, only shows that access to syllabic units may not be frequency-sensitive. It does not rule out the possibility that speakers make use of syllables in the course of the speech production process. Lexico-statistical analyses revealed that syllables in languages like Dutch, English, or German differ greatly in frequency. In Dutch, 85% of all syllable tokens occurring in the CELEX lexical database for Dutch can be produced using the set of the 500 most frequent syllable types (Schiller, Meyer, Baayen, & Levelt, 1996). This adds plausibility to the notion of a mental syllabary. The mental syllabary is a hypothetical repository of precompiled articulatory motor programs for (high-frequency) syllables, to which speakers may have access during the production of speech (Levelt & Wheeldon, 1994). The articulatory motor programs are conceived of as *gestural scores*, i.e., representations which specify the phasing of individual gestures.

Ferrand, Segui, and Grainger (1996) found a syllable priming effect in French. Words, nonwords, and pictures were named significantly faster when they were preceded by a visually masked prime that exactly corresponded to their first syllable than when the prime was one segment shorter or longer than the target's first syllable. Ferrand et al. argued that their syllable priming effect was located in the output phonology. Hence, they claim that syllables play a role at the output level of speech production. However, this finding could not be replicated for Dutch. Instead, only a segmental overlap effect was found, i.e., the facilitation effect for word and picture naming increased with increasing overlap between prime and target (Schiller, submitted). Possibly the syllable priming effect in French originated during the perceptual processing of the prime rather than during speech production proper.

In Levelt's (1989; Levelt et al., accepted) model of speech production, syllables are conceived of as articulatory units. The syllable structure of word forms is not specified in the mental lexicon, and syllables are created relatively late in the speech production process. During phonological encoding, segmental information, i.e., the phonological segments constituting the word, and metrical information are retrieved separately (Roelofs & Meyer, in press). The metrical information specifies a word's number of syllables and its lexical stress. At the stage of segment-to-frame association spelled-out segments that are not specified for their syllabic position but only for their serial position within a morpheme are associated to metrical frames in accordance with universal and language-specific syllabification rules (Roelofs, 1996). The resulting phonological syllables are phonetically encoded on a segment-by-segment basis or via the retrieval of the corresponding gestural score from a mental syllabary. The syllabic gestural scores are passed on to the articulatory system, which transforms them into the appropriate neuro-muscular commands and executes them.

Very little is known about the exact mechanisms that underly the articulatory control of speech production, and Levelt's model does not offer a theory of articulatory execution. The model of *gestural phonology* is more explicit about the processes related to phonetic encoding and articulation (Browman & Goldstein, 1986, 1987, 1989, 1990, 1992). In this framework, the customary distinction between phonology and phonetics is given up. The activity of the articulatory motor system is described in terms of underlying *articulatory gestures*. Articulatory gestures are the basic units of phonological contrast, and at the same time they characterize articulatory events, i.e., movements in space and time. These articulatory events consist of formations and releases of constrictions in the vocal tract. The dimensions of these constrictions, e.g., constriction location and constriction degree, are specified by *tract variables* (e.g., lip protrusion, tongue tip constriction location, etc.). The targets of the vocal tract variables are achieved by the *model articulators* representing relatively independent articulatory subsystems of the vocal tract, e.g., lips, tongue tip, tongue body, jaw, velum, etc. The model articulators are located on different *articulatory tiers*. Within gestural phonology, a *gestural score* takes care of the coordination of the articulatory gestures, i.e., it specifies the phasing between individual gestures in time and space.

It is still an open issue whether or not syllables play a role in the timing of articulatory gestures. In Levelt's model of speech production syllables are the basic units of articulation. Articulatory data showed, however, that the articulatory timing of segments is not always well correlated with their syllable affiliation (Browman & Goldstein, 1988; Byrd, 1995). Browman and Goldstein (1988) investigated the articulatory trajectories for $V_1C_1(C_2)(C_3)V_2$ pseudoword sequences. "Word" boundaries occurred before or after C_1 such that the strings only differed in the presumed syllable affiliation of C_1, e.g., [pi.pats] vs. [pip.adz], [pi.spats] vs. [pis.pats], or [pi.splats] vs. [pis.plats]. Browman and Goldstein (1988) defined an *anchor point*, which corresponded to the attainment of the target of the first postvocalic consonant and to the acoustic offset of the vowel, and a *C-center*, which was defined as the central point of timing of the articulatory gestures involved in the production of a consonant (sequence). The C-center was computed by determining the temporal midpoints of the plateaus for the peak displacement of the consonantal gestures in a sequence and then computing the arithmetic mean of all midpoints. Browman and Goldstein found that the C-centers of singleton onsets as well as onset clusters were timed with respect to the tautosyllabic anchor point. This was called *global timing* because it was always the C-center of the entire onset sequence that showed the most stable timing relative to the anchor point. Stability was defined in terms of the standard deviation of the temporal interval between the anchor point and the C-center across utterances. Singleton codas or codas followed by an onset were shown to be timed relative to a preceding vowel with their left edge, i.e., the achievement of the target position of their leftmost consonant. This was called *local timing* because no matter how long the sequence was, it was always the left edge of the first consonant that was timed most stably relative to the preceding vowel regardless of its underlying syllable affiliation. This suggested that syllable affiliation showed no effect on articulatory timing.

However, Browman and Goldman did not investigate the timing of codas or coda plus onset sequences relative to the following vowel. Therefore, it was not clear whether the global timing relationship between onsets and the following vowel was an effect of underlying syllable affiliation or of some special property of onset consonants. To test whether the CV-timing relationship, i.e., the timing relationship between a consonant (sequence) and the following vowel, is affected by the canonical syllable affiliation of the consonants, Byrd (1995) examined the articulatory movements in English consonant sequences using electropalatography (EPG). She investigated coda and coda plus onset sequences such as [baks.ab] vs. [baks.kab]. Byrd (1995) found that the CV-timing relationship for sequences including coda consonants is dependent on the underlying syllable affiliations of the consonants. For coda plus onset sequences the most stable CV-timing relationship was from the C-center of the onset consonant to the following vowel rather than from the C-center of the whole sequence. Byrd's results for the VC timing were more ambiguous. The data of one speaker supported Browman and Goldstein's (1988) result that the left edge of a sequence is most stably timed with a preceding vowel. For three other speakers, however, it was the C-center of the coda cluster (of a coda plus onset sequence) that was the most stable VC-timing point. The center of the tautosyllabic consonants seems to play an important role for the articulatory timing relationships (although this was less clear in the case of the VC timing), i.e., the underlying syllable affiliations showed some effect on the timing of consonant sequences in English. Still, taken together, the results of the studies by Browman and Goldstein (1988) and Byrd (1995) are inconclusive with respect to the effect of syllable affiliations in articulation.

The present study investigated whether the articulatory timing of intervocalic consonants is affected by their syllable affiliation. In particular the *syllable timing hypothesis* was tested, which predicts that segments within a syllable are more stably timed relative to each other than segments that belong to different syllables. This hypothesis is derived from Levelt's speech production model. The rationale behind it is that if syllables are articulatory motor units, then the motor coordination of segments that belong to the same unit should be less variable than the coordination of segments from different units. According to this hypothesis the articulatory timing between two consonants, e.g., /f/ and /k/, should be more stable for CVC items, e.g., *fak.tor*, since both segments are in the same syllable, than for CV items, e.g., *fa.kir*, because /f/ and /k/ belong to different syllables.[1] CV[C] items, such as *fa[kk]el*, should either pattern somewhere in between the previous two item categories or the timing between /f/ and /k/ should be even more variable than for the CV items because it is not clear with which syllable /k/ is affiliated in the case of CV[C] items.

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[1] *Syllable boundaries are marked by dots and ambisyllabic consonants appear between square brackets.*

EXPERIMENT

Method

Speech materials. In previous research on the role of the syllable in Dutch speech production (see Schiller, Meyer, & Levelt, 1997; Schiller, submitted) three categories of items were investigated, i.e., CVC words such as *faktor* /fɑk.tɔr/ ('factor') beginning with a CVC syllable, CV words like *fakir* /fa.kir/ ('id.'), and CV[C] words such as *fakkel* /fɑ[k]əl/ 'torch', which have an ambiguous syllable boundary. In this study ten item triplets were selected such that the items of each triplet overlapped in the first three segments (disregarding vowel length) but differed with respect to syllable structure, as in the case of *faktor - fakir - fakkel.* Dutch phonological structure does not allow for short vowels to occur in open syllables (*Branching Rhyme Constraint,* BRC; Booij, 1995; Lahiri & Koreman, 1988). That is why all CV words have a long vowel in the first syllable and all CVC words have an intervocalic consonant cluster (C-cluster). All items were stressed on the first syllable. The items are listed in Appendix A.

Despite the fact that the items of a triplet do not completely agree in phonological structure we preferred to use natural language materials over pseudowords for two reasons. First, there may be differences in the articulatory timing between real words and pseudowords. Marchal and Courtois (1996), for instance, compared electropalatographic data from one CVC sequence appearing in nonwords, real words, and sentences and found large differences in the linguopalatal contact patterns between the nonsense words and the words. They concluded "that nonsense words cannot be used to deduce the articulatory phenomena specific to continuous speech units such as real words and sentences" (p. 22). Second, most of the items used in this study have been used before in other experiments investigating the role of the syllable in speech production (Schiller, submitted; Schiller et al., 1997). Thus, earlier experiments with the materials showed that the items could be used to investigate syllabic effects in speech production.

Participants. Four participants (three females, one male) drawn from the participant pool of the Max Planck Institute for Psycholinguistics took part in the experiment in exchange for pay. All of them were native speakers of Dutch. None of them reported any speech or hearing disorders.

Procedure. Participants were seated in a chair. They wore a helmet necessary to monitor their articulatory movements (see Apparatus section).

The helmet was attached to a suspending device to improve the stability of its position on the participant's head and to compensate for a substantial portion of the helmet's weight (Alfonso, Neely, van Lieshout, Hulstijn, & Peters, 1993; van Lieshout, Alfonso, Hulstijn, & Peters, 1995). On each trial participants received one test item. Test items were presented visually on sheets of paper. Participants waited until the experimenter gave a *go*-signal, and then produced multiple repetitions of the test item for a period of ten seconds. The speech rate was self-selected. An inter-trial interval of approximately 20 seconds was needed to save the data on disc and to prepare the system for the next trial. The recording session lasted approximately 40 minutes. The entire experiment took about one and a half hours.

Before the recording session participants' occlusal planes were recorded. Participants were instructed to bite on a plate on to which two receiver coils were attached in the midline. The position of the two coils was recorded and served as an individual anatomical reference plane to which the data obtained in the experiment could be rotated in order to be able to compare data across subjects. Furthermore, immediately before and after data collection the static receiver coil positions were recorded for an informal check of the system's stability during the experiment.

Design. Each participant produced all items, which were combined into one test block. The order of item presentation was randomized individually for each participant with the restriction that items belonging to the same triplet or to the same item category were separated by at least one trial.

Apparatus. Tongue, lip, and jaw movements were monitored using EMMA. EMMA is a biologically save movement tracking system that can be used to collect movement data for relatively long periods of time (Schönle, 1988; Schönle, Gräbe, Wenig, Höhne, Schrader, & Conrad, 1987). The AG100 EMMA system (Carstens Medizinelektronik, Göttingen, Germany) used in this study consists of three transmitter and five receiver coils (for details see Alfonso et al., 1993; van Lieshout et al., 1995; Perkell, Cohen, Svirsky, Matthies, Garabieta, & Jackson, 1992; Recasens & Romero, 1997; Tuller, Shao, & Kelso, 1990). The transmitter coils are mounted on a helmet below and in front of the jaw, above and in front of the forehead, and below and behind the occiput with their axes perpendicular to the midsagittal plane (see Figure 1). All transmitter coils are excited sinusoidally at three different frequencies to generate an inhomogeneous electromagnetic field (Schönle et al., 1987). The receiver coils are placed on the articulators in the midsagittal plane with the same orientation as the transmitter coils. The electromagnetic field generated by the transmitters induces an alternating signal in the receivers. Since the strength of this signal is inversely proportional to the cube of the distance from the transmitter, the distance between receiver and transmitter coils can be determined from the strength of the signal in the receivers.

The five receiver coils were placed in the midsagittal plane on the following articulators: Coil 1 was attached to the tongue tip (TT) approximately 1.0 cm posterior to the apex, coil 2 was placed on the tongue body (TB) approximately 4.0 cm posterior to the apex, coil 3 was attached to the upper lip (UL) just above the vermillion border, coil 4 to the lower lip (LL) just beneath the vermillion border, and coil 5 to the jaw (JW). The JW coil was attached to a mouth piece[2] which fitted on the lower incisors. This location guarantees the highest measurement accuracy since contamination with skin movement artefacts is avoided. The receiver coils are 2 mm in diameter and interfered very little with articulation. Cyano-Veneer surgical glue, an ethylcyanoacrylat composition (Meyer-Haake, Medizin- und Dentalhandels GmbH), was used to attach the coils on the tongue surface, and Skin-Bond cement, a fluid latex composition (Smith & Nephew, USA), was used to fixate the lip coils. The receiver coils were connected to the AG100 system with fine wires. The local field strengths induced in the receivers lie within the microvolt to millivolt range (Schönle et al., 1987) and present a minimal risk to humans (Alfonso et al., 1993).

The calibration of the EMMA system was done according to a standard procedure described in Alfonso et al. (1993) and Hoole (1993) with some slight adaptations. The five receiver coils were placed into a holder which in turn was placed into a calibration device. Using this device each coil can be placed in the geometric center of the measuring area as defined by the positions of the transmitter coils in the helmet, exactly aligned to the midsagittal plane. For each coil in that position, the signal values were recorded and stored for subsequent calculation of voltage-to-distance values. This method is less time consuming, but in practice it is not less accurate than the standard method.

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[2] *The mouth piece is made from Vinyl Polysiloxane impression material putty (3M Express STD). For each subject, a small amount of putty was placed around the lower incisors and subsequently formed by hand to fit the exact contours of the teeth. This way a thin layer was formed which fitted tightly and could not move once put into position. Participants got used to the mouth piece after a short adaptation period of about 10-15 min.*

The EMMA AG100 system transduces horizontal and vertical articulatory movements with a high spatial and temporal resolution. The spatial resolution of the system is < 0.25 mm (Alfonso et al., 1993; Rouco & Recasens, 1996; Tuller et al., 1990). The temporal resolution is adjustable in the AG100 system. In this study the movement data were recorded at a sampling rate of 400 Hz. Simultaneously with the monitoring of the articulatory movements acoustic recordings were made at a sampling rate of 16 kHz. Speech and movement data were digitized simultaneously and aligned by means of the AG100 system software.

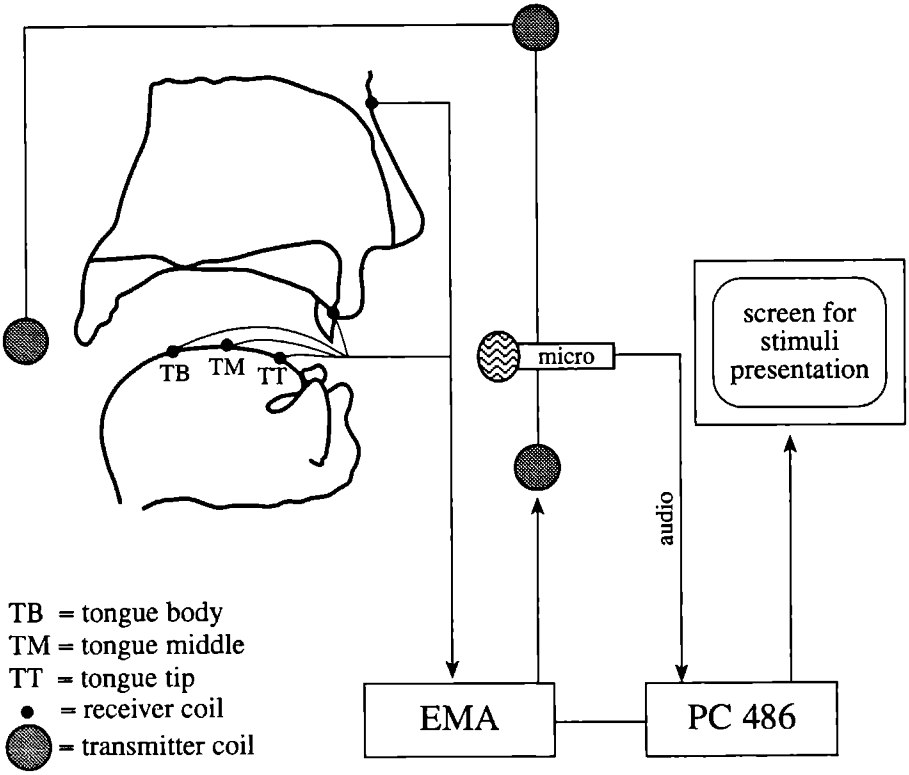

Figure 1 *Overview of the experimental set up indicating the location of the transmitter and receiver coils.*

Data analysis

The computer routines used for the analysis of the articulatory data were devised in close correspondence to the XHADES (Haskins Analysis/Display/Experiment/ System) software developed at Haskins Laboratories (New Haven, CT, USA) (see Rubin, MacEachron, Tiede, & Maverick, 1991). The analysis routines were integrated into the waves/ESPS speech analysis package (Entropics Inc.), which allows the simultaneous display of the time-aligned acoustic and articulatory signals (see Figure 2).

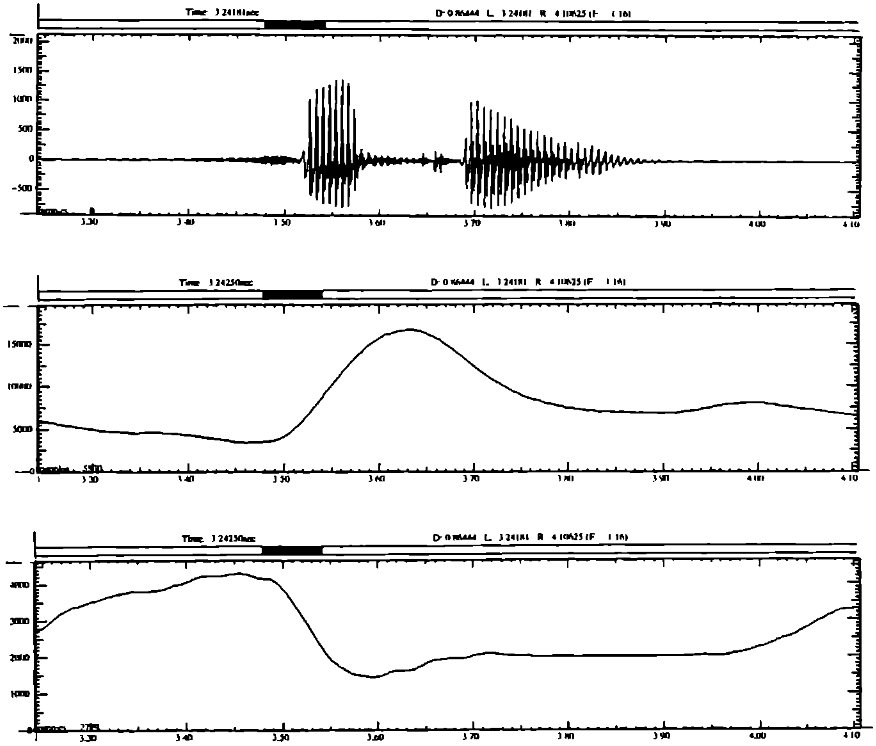

Figure 2 *Display of the speech and movement signals for one token of the experimental trial 'fakkel' produced by participant 3. The upper panel displays the acoustic signal, the middle panel the tongue body movement (recorded from coil TB), and the lower panel the jaw movement (recorded from coil JW).*

Preprocessing. EMMA movement data collected during the experiment were digitally low-pass filtered and rotated to parallel the occlusal reference plane. After the data had been copied to UNIX platforms, a drift in the acoustic data, i.e., a low-frequency modulation of the signal, was removed using a high-pass filter. The original MS-DOS EMMA data files were demultiplexed into ten separate files (five receiver coils x two dimensions). To derive independent tongue and lower lip signals, the JW receiver coil was subtracted digitally from the TT, the TB, and the LL receiver coil signals (Gracco, 1988; Gracco & Abbs, 1986).

Analysis. The articulatory analyses were based on the displacement data recorded by the coils which were assumed to most directly reflect the articulatory movement for the constriction gestures under investigation. For /p/ this was the upper lip (UL) and the lower lip (LL) coils, for a /t/ it was the tongue tip (TT) coil, and for a /k/ it was the tongue body (TB) coil. Previous research by Gracco and Abbs (1986, 1988; Gracco, 1988) and Hoole, Mooshammer, and Tillmann (1994) showed that velocity profiles play an important role for the articulatory control during vowel production. Here, we used the velocity characteristics of vertical tongue and lip movements to investigate the articulatory timing of intervocalic consonants.

For the analysis the second through ninth token of each test item were considered. First, the movement signals of each trial were smoothed using a weighted triangular filter function. To determine the articulatory timing of the intervocalic consonants, two landmarks were then kinematically determined in each test word. The first landmark was called anchor point C_1 and was defined as the articulatory release of the first consonant. C_1 corresponded to the point in time when the articulator(s) forming the release for the onset consonant reached the maximum in the movement signal. The velocity was derived from the displacement signal using a standard differentiation algorithm. The second landmark was called C_2 and defined as the articulatory target position of the intervocalic consonant. An articulatory target is generally conceived of as a point of minimum velocity (see, e.g., Perkell et al., 1992). In this study, C_2 corresponded to the (temporal) midpoints of the consonantal centers (C-centers) of the corresponding consonantal gestures. At low to moderate speech rates consonantal gestures often display a plateau-like shape, i.e., a quasi-steady state phase, rather than a peak (see middle panel of Figure 3).[3] As a consequence, the absolute point of zero crossing is not appropriate to determine the articulatory target position.

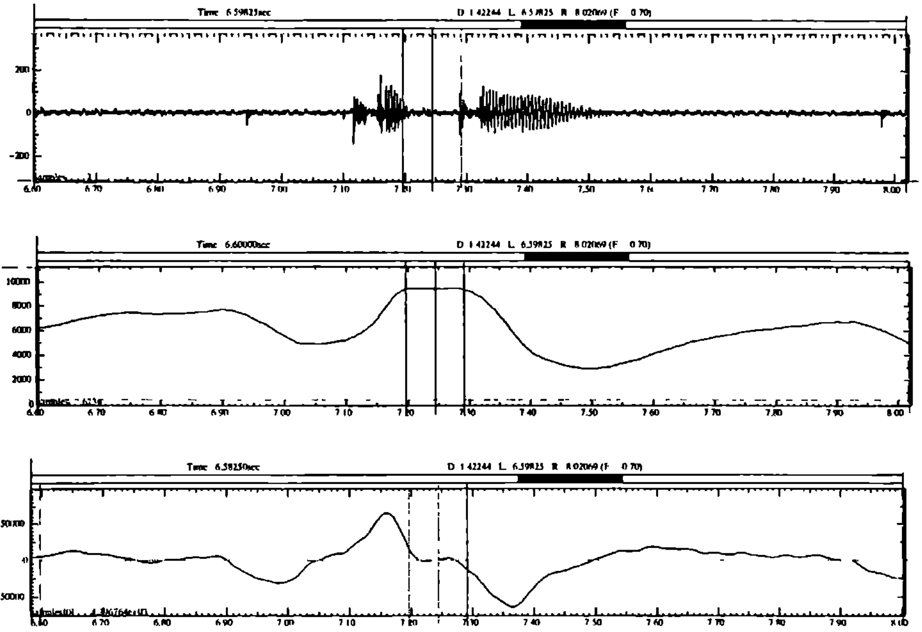

Figure 3 *Display of the speech signal, movement signal of the tongue tip, and velocity profile of the tongue tip movement for one token of the experimental trial 'ketting' produced by participant 2. The upper panel displays the acoustic signal, the middle panel the tongue tip movement (recorded from coil TT), and the lower panel the velocity profile of the tongue tip movement. Vertical lines indicate the onset (left line) and the offset (right line) of the velocity interval the temporal midpoint of which (middle line) was defined as the C-center of the corresponding gesture.*

Therefore, to determine the C-center of consonantal gestures we adapted a procedure used by Hoole et al. (1994) to define the displacement plateau of the intervocalic consonants. Intervals in the first derivative of the corresponding

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[3] *In this study, participants produced on average between 10 and 12 repetitions of each item within the interval of 10 seconds. Accordingly, speech rate, i.e., the number of produced syllables divided by the entire production interval, was relatively low (participant 1: 2.2 syl/sec; participant 2: 2.0 syl/sec; participant 3: 2.4 syl/sec; participant 4: 2.1 syl/sec).*

position signal were demarcated by points in time where for a given cycle both positive and negative velocities became lower than 20% of the peak velocity. Thus, the onset of the interval corresponded to the point in time when the velocity fell below 20% of the peak velocity of a given cycle, whereas the offset corresponded to the point in time when the velocity rose above 20% of the peak velocity (see lower panel of Figure 3). The C-center was defined as the temporal midpoint of the interval between the two markers, in most cases corresponding to the peak displacement in the position signal.

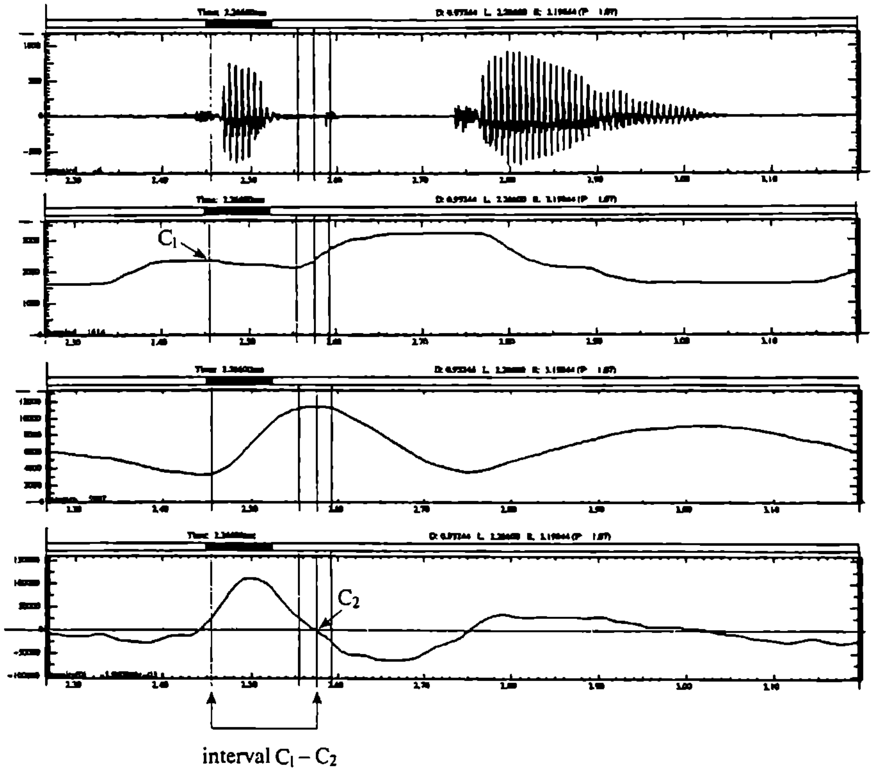

Figure 4 *Display of the speech signal, the jaw and tongue body movement signal, and the velocity profile of the tongue body movement for one token of the experimental trial 'faktor' produced by participant 3. The upmost panel displays the acoustic signal, the upper middle panel the jaw movement (recorded from coil JW), the lower middle panel the tongue body movement (recorded from coil TB), and the lowmost panel the velocity profile of the tongue body movement. The anchor point* C_1 *and the C-Center* (C_2) *as well as the interval* C_2-C_1 *are indicated in the figure.*

The stability of the articulatory timing of the intervocalic consonant was expressed in the temporal relation between C_1 and C_2. To quantify stability we measured the time interval between C_1 and C_2 for each token (see Figure 4). The standard deviation (SD) of the mean length of this interval C_2-C_1 for the eight repetitions of each test item was taken as a measure of stability.

Furthermore, the duration of the vowel in the first syllable (V_1) and of the intervocalic consonant was determined in the acoustic signal by means of sonagraphic analyses.

Results

The SD of the interval C_2-C_1 for the eight repetitions was determined per item to compare the stability of the articulatory timing within each item. The means of the SD's per participant and category are shown in Table 1.

As can be seen in Table 1, only for one participant the SD was markedly smaller for the CVC items than for the remaining item types. One-way repeated measurements were run for each participant to compare the three Item Categories (CV, CVC, or CV[C]), but the main effect of Item Category was not significant for any of the four participants (participant 1: *F* (2,27) = 2.28, MS_e = 240.61, n.s.; participant 2: *F* (2,27) < 1; participant 3: *F* (2,27) < 1; participant 4: *F* (2, 27) < 1).

Table 1 MEAN SD'S OF THE INTERVAL C_2-C_1 PER PARTICIPANT AND ITEM CATEGORY.

	Mean SD of the interval C_2-C_1 (in ms)		
participant	CV items	CVC items	CV[C] items
1	28	15	29
2	55	47	56
3	31	36	31
4	38	38	35

However, the length of the first vowel differed between the three Item Categories. The mean vowel length for CVC items was 78 ms and 80 ms for

CV[C] items, whereas for CV items it was 167 ms. A one-way analysis comparing the vowel length differences revealed a main effect of Item Category (F (2,957) = 803.14, MS_e = 1022.33, $p < .001$). As a consequence of this vowel length difference the mean interval C_2-C_1 was longest for the CV items. Table 2 lists the mean length of the C_2-C_1 interval per participant and item category.

Furthermore, the mean length and the SD of the interval C_2-C_1 correlated significantly for three of our four participants (participant 1: r = .50, p = .005; participant 2: r = .42, p = .022; participant 3: r = .64, $p < .001$; participant 4: r = .17, n.s.). Therefore, we ran analyses of covariance entering the mean length of the interval C_2-C_1 as a covariate in order to take into account the vowel length differences between the Item Categories. However, except for one participant, the differences of the SD's between the categories were still not significant (participant 1: F (2,26) = 1.46, MS_e = 197.49, n.s.; participants 2: F (2,26) < 1; participant 3: F (2,26) = 5.88, p = .008; participant 4: F (2,26) < 1).[4]

Table 2 MEANS OF THE INTERVAL C_2-C_1 PER PARTICIPANT AND ITEM CATEGORY.

	Means of the interval C_2-C_1 (in ms)		
participant	CV items	CVC items	CV[C] items
1	246	155	184
2	330	281	258
3	308	203	178
4	259	223	193

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[4] *Analyses of variance using the quotient of the SD and the mean of the C_2-C_1 interval as a coefficient of variation revealed the same pattern of results (participant 1: F (2,27) = 1.47, MS_e < .01, n.s.; participant 2: F (2,27) < 1; participant 3: F (2,27) = 5.29, MS_e < .01, p = .012; participant 4: F (2,27) < 1).*

Discussion

The results did not provide any evidence for the hypothesis that the syllable affiliation of an intervocalic consonant plays a role in articulatory timing. The variability of the articulatory timing in different Item Categories did not show a stable pattern across participants. The fact that the timing of consonants within a syllable was not more stable than the timing of onset consonants of successive syllables came as a surprise. This result clearly contradicts the syllable timing hypothesis according to which the variability of the articulatory timing should be highest for the CV items since C_1 and C_2 belong to different syllables. Also, the fact that items including ambisyllabic consonants did not significantly differ from the other two Item Categories with respect to the articulatory timing of the intervocalic consonant was unexpected.

SUMMARY AND CONCLUSION

The experiment reported in this study had two major goals. The first goal of this study was theoretically motivated. Syllables are seen as articulatory motor units in Levelt's model of speech production. Since there is very limited on-line evidence for the use of syllables during phonological encoding in speech production, we investigated whether the phonological syllable affiliation of intervocalic consonants is reflected on the articulatory output level, i.e., at the stage of motor execution. The results, however, revealed no significant differences between the timing of segments within a syllable and the timing of the same segments when a syllable boundary occurred between them. But since the difference in vowel length is problematic for comparisons between items, future research may focus on the articulatory timing of onset and coda consonants in monosyllables with short vs. long vowels.

The second goal was of practical nature. EMMA is a tool for the observation of articulatory movements during speaking (Schönle et al., 1987; Tuller et al., 1990), which has so far largely been used in clinical settings. Very few studies have used this method to investigate normal speech production. Even fewer studies have used natural speech materials - pseudoword stimuli of the type used by Browman and Goldstein (1988) predominated. Our approach had an exploratory character testing the feasibility of the method in a study of normal speech motor timing. We wanted to test whether kinematic data could be used to shed more light on the question whether syllables play a role in speech production. Although we did not obtain clear results, this study increased our confidence in the method.

REFERENCES

ALFONSO, P. J., NEELY, J. R., VAN LIESHOUT, P. H. H. M., HULSTIJN, W., & PETERS, H. F. M. (1993). Calibration, validation, and hardware-software modifications to the Carstens EMMA system. *Haskins Laboraties Status Report on Speech Research*, **SR-114**, 101-112.

BOOIJ, G. (1995). *The Phonology of Dutch*. Oxford: Clarendon Press.

BROWMAN, C. P. & GOLDSTEIN, L. (1986). Towards an articulatory phonology. *Phonology Yearbook*, **3**, 219-252.

BROWMAN, C. P. & GOLDSTEIN, L. (1987). Tiers in articulatory phonology, with some implications for casual speech. *Haskins Laboratories Status Report on Speech Research*, **SR-92**, 1-30.

BROWMAN, C. P. & GOLDSTEIN, L. (1988). Some notes on syllable structure in articulatory phonology. *Phonetica*, **45**, 140-155.

BROWMAN, C. P. & GOLDSTEIN, L. (1989). Articulatory gestures as phonological units. *Phonology*, **6**, 201-251.

BROWMAN, C. P. & GOLDSTEIN, L. (1990). Gestural specification using dynamically-defined articulatory structures. *Journal of Phonetics*, **18**, 299-320.

BROWMAN, C. P. & GOLDSTEIN, L. (1992). Articulatory phonology: An overview. *Phonetica*, **49**, 155-180.

BYRD, D. (1995). C-centers revisited. *Phonetica*, **52**, 285-306.

FERRAND, L., SEGUI, J., & GRAINGER, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, **35**, 708-723.

GRACCO, V. L. (1988). Timing factors in the coordination of speech movements. *The Journal of Neuroscience*, **8**, 4628-4639.

GRACCO, V. L. & ABBS, J. H. (1986). Variant and invariant characteristics of speech movement planning. *Experimental Brain Research*, **65**, 156-166.

GRACCO, V. L. & ABBS, J. H. (1988). Central patterning of speech movement timing. *Experimental Brain Research*, **71**, 515-526.

HOOLE, P. (1993). Methodological considerations in the use of electromagnetic articulography in phonetic research. *Forschungsberichte des Instituts für Phonetik und Sprachliche Kommunikation der Universität München* [*Status Reports of the Institute of Phonetics and Verbal Communication of the University of Munich*], **31**, 43-64.

HOOLE, P., MOOSHAMMER, C., & TILLMANN, H. G. (1994). Kinematic analysis of vowel production in German. *Proceedings of the third*

International Conference on Spoken Language Processing, Yokohama 1994 (pp. 53-56).

LAHIRI, A. & KOREMAN, J. (1988). Syllable weight and quantity in Dutch. In H. Borer (Ed.), *Proceedings of the 7th West Coast Conference of Formal Linguistics 1988* (pp. 217-228). Stanford, CA: Center for the Study of Language and Information.

LEVELT, W. J. M. (1989). *Speaking. From Intention to Articulation.* Cambridge, MA: MIT Press.

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

LEVELT, W. J. M., ROELOFS, A., & MEYER, A. S. (accepted). A theory of lexical access in speech production. *Behavioral and Brain Sciences.*

VAN LIESHOUT, P. H. H. M., ALFONSO, P. J., HULSTIJN, W., & PETERS, H. F. M. (1995). Electromagnetic midsagittal articulography (EMMA). In F. J. Maarse, A. E. Akkerman, A.N. Brand, L. J. M. Mulder, & M. J. van der Stelt (Eds.), *Computers in Psychology: Applications, Methods, and Instrumentation* (pp. 62-76). Lisse: Swets & Zeitlinger.

MARCHAL, A. & COURTOIS, F. (1996). Study of the articulatory realization of /l/ in nonsense words, real words, and sentences. In *Proceedings of the 1st ESCA Tutorial and Research Workshop on Speech Production Modelling: From Control Strategies to Acoustics & 4th Speech Production Seminar: Models and Data, Autrans, France, May 20-24, 1996* (pp. 21-24). Grenoble: Institut de la Communication Parlée.

PERKELL, J. S., COHEN, M. H., SVIRSKY, M. A., MATTHIES, M. L., GARABIETA, I., & JACKSON, M. T. T. (1992). Electromagnetic midsagittal articulometer systems for transducing speech articulatory movements. *Journal of the Acoustical Society of America*, **92**, 3078-3096.

RECASENS, D. & ROMERO, J. (1997). An EMMA study of segmental complexity in alveolopalatals and palatalized alveolars. *Phonetica*, **54**, 43-58.

ROELOFS, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, **35**, 854-876.

ROELOFS, A. & MEYER, A. S. (in press). Metrical structure in planning the production of spoken words. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

ROUCO, A. & RECASENS, D. (1996). Reliability of electromagnetic midsagittal articulometry and electropalatography data acquired simultaneously. *Journal of the Acoustical Society of America*, **100**, 3384-

3389.

RUBIN, P., MACEACHRON, M., TIEDE, M., & MAVERICK, V. (1991). *HADES - Haskins Analysis/Display/Experiment/System: Documentation.* New Haven: Haskins Laboratories.

SCHILLER, N. O. (submitted). The effect of visually masked syllable primes on the naming latencies of words and pictures. *Journal of Memory and Language.*

SCHILLER, N. O., MEYER, A. S., BAAYEN, R. H., & LEVELT, W. J. M. (1996). A comparison of lexeme and speech syllables in Dutch. *Journal of Quantitative Linguistics*, **3**, 8-28.

SCHILLER, N. O., MEYER, A. S., & LEVELT, W. J. M. (1997). The syllabic structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, **40**, 103-140.

SCHONLE, P. W. (1988). *Elektromagnetische Artikulographie. Ein neues Verfahren zur klinischen Untersuchung der Sprechmotorik [Electromagnetic articulography. A new method for the clinical investigation of speech motor action]*. Berlin: Springer.

SCHONLE, P. W., GRABE, K., WENIG, P., HOHNE, J., SCHRADER, J., & CONRAD, B. (1987). Electromagnetic articulography: Use of alternating magnetic fields for tracking movements of multiple points inside and outside the vocal tract. *Brain and Language*, **31**, 26-35.

TREIMAN, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, **15**, 49-74.

TREIMAN, R. & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

TULLER, B., SHAO, S., & KELSO, J. A. S. (1990). An evaluation of an alternating magnetic field device for monitoring tongue movements. *Journal of the Acoustical Society of America*, **88**, 674-679.

APPENDIX

Appendix A SPEECH MATERIALS USED IN THE EXPERIMENT.

Target Word Structure		
CV items	CVC items	CV[C] items
balie ('counter')	balsem ('balsam')	ballast ('id.')
fakir ('id.')	faktor ('factor')	fakkel ('torch')
haken ('hooks')	haksel ('chaff')	hakken ('hoes')
hamer ('hammer')	hamster ('id.')	hammen ('hams')
kamer ('room')	kamfer ('camphor')	kammen ('combs')
ketel ('kettle')	ketjap ('soja sauce')	ketting ('chain')
molen ('mill')	molmig ('rotten')	mollen ('moles')
Pasen ('Easter')	paspoort ('pasport')	passer ('compass')
peluw ('pillow')	pelgrim ('pilgrim')	pellen ('peels')
polo ('id.')	polder ('id.')	pollen ('bunch')

GENERAL CONCLUSIONS

CHAPTER 6

Levelt's speech production model makes three important claims about the role of syllables in the speech production process. First, it is assumed that word form representations in the mental lexicon are not syllabified. The main argument for this assumption is that syllable boundaries in connected speech often differ from the words' canonical syllabification. For example, the coda /d/ in *demand* /di.mɑnd/ becomes an onset /d/ in *demand it* /di.mɑn.dɪt/. In the linguistic literature these syllable boundary shifts are called *resyllabification* (Booij, 1995). If syllable boundaries vary depending on the context in the speech output, it does not make much sense to assume fully syllabified representations at the lexical level. Second, as a corollary of the first claim, it is assumed in the model that syllables arise at a relatively late point in time in the speech production process, i.e., during prosodification. At this level, segments and metrical frames, which have been retrieved independently of each other, are combined. Segments are not specified for their syllabic positions but only for their serial positions within morphemes (Roelofs, 1996). It is only at the stage of *segment-to-frame association* that the syllabic position of a segment, e.g., onset or coda, is determined according to the syllabification rules of the language. This process of syllabification results in fairly abstract phonological syllables. Third, in addition to these *phonological syllables* the model assumes *phonetic syllables*, i.e., packages of articulatory gestures stored in a *mental syllabary* (Levelt, 1989; see also Crompton, 1981 for a related proposal). The phonetic syllables are conceived of as articulatory motor units, i.e., *execution units*, rather than *planning units*. Levelt and Wheeldon (1994) obtained experimental evidence supporting the notion of a mental syllabary. The crucial finding was that words of similar word frequency were named faster when they consisted of high-frequency syllables than when they were made up of low-frequency syllables. A mental syllabary would greatly reduce the computational load in the speech production process since the motor programs for syllables would not have to be assembled segment by segment but could be retrieved as whole units.

How do the results presented in Chapters 2 to 5 relate to the assumptions put forward by the model? The conclusions that can be drawn from the experimental results about the syllable's role in speech production are the following: The lexico-statistical investigation reported in Chapter 2 provided some evidence against fully syllabified representations at the lexical level. The application of phonological sentence-level rules to a large phonologically transcribed Dutch newspaper corpus showed that resyllabification is quite a frequent phenomenon in connected speech. In our *worst case scenario* approach on average every fifth word was affected by resyllabification. Therefore, it seems plausible that isolated word form representations in the mental lexicon are not syllabified because otherwise syllable structure has to be recomputed for a substantial number of words.

The claim that syllables arise relatively late in the speech production process implies that syllables are not used as planning units during the early process of phonological encoding. Baumann (1995) investigated the time course of syllabification in Dutch, but she neither found evidence for early syllabification (there was no syllable match effect when primes were presented at early SOAs) nor for late syllabification (there was no syllable match effect when primes were presented at late SOAs). By contrast, Ferrand, Segui, and Grainger (1996) recently reported a syllable priming effect in French suggesting that syllables may play a role at the phonological output level in speech production. However, applying the masked syllable priming paradigm developed by Ferrand et al. (1996) to Dutch materials failed to produce syllable priming effects (see Chapter 4). Instead, significant length effects were found. Long primes were more efficient than short primes, but the facilitation effects were independent of the syllabic relationship between prime and target. On the assumption that the masked syllable priming paradigm taps into an early stage of phonological encoding, this finding is consistent with the model. The model predicts that at that stage there should only be segmental but no syllabic priming effects. The results of the masked syllable priming study are compatible with the absence of a syllable monitoring effect in Dutch speech perception (Cutler, in press). Presumably, the syllable priming effect in French is not a "pure" production effect but originates on the perceptual side. The visually masked prime preactivates the segments, which are already specified for their syllable position in French. Thus, the perceptual information contained in the prime preactivates not only the segments but also the corresponding syllable, which results in a syllable priming effect in production. This interpretation seems plausible on the basis of the strong syllable monitoring effect found for French by Mehler, Dommergues, Frauenfelder, & Segui (1981). In the lexical decision task the syllable priming effect disappears since output phonology of the target word is not involved in this task.

The failure to obtain a syllable priming effect in the masked priming experiments suggests that the task did not tap into the process of syllabification. Thus, it may be premature to conclude that syllables do not play any role at all in the process of speech production. According to Levelt's model it should still be possible to obtain a syllable priming effect in Dutch speech production with methods that tap very late processing stages of phonological encoding. Further research is needed to address the issue of late syllabification.

If syllables are computed on-line in accordance with the syllabification rules of the language, one may expect to observe some variability in the output of the syllabification process. The results of the metalinguistic syllabification experiments showed that Dutch speakers indeed differ in their intuitions about the syllabification of certain words (see Chapter 3). Although they are sensitive to the language-specific constraints on syllable structure and generally obey these constraints in syllabification, they were quite variable in syllabifying words including ambisyllabic consonants in the syllable reversal task. Furthermore, the fact that it was possible to bias the syllabification of words with ambiguous syllable boundaries by presenting them in the context of words with clear syllable boundaries provided additional support for the assumption that a word's syllable structure is computed by rule rather than represented in the lexicon.

Levelt's model assumes that articulatory motor units of syllabic size form the basic units of articulation. Based on speech error analyses, Crompton (1981) suggested that syllables may play an important role in speech production. Levelt and Wheeldon (1994) discovered a syllable frequency effect in speech production which supports the assumption of syllablic units stored in a mental syllabary. This idea gained some plausibility by the fact that speakers can generate the vast majority (e.g., 85% in the case of Dutch) of all syllables they produce with only 5% of all syllable types. This means that speakers use a relatively small set of high-frequency syllables to produce the largest part of their entire speech output. However, recent experimental research showed that the syllable frequency effect is not well replicable

(Levelt, Roelofs, & Meyer, accepted). Therefore, it is still an open question whether or not there is a mental syllabary.

From a theoretical point of view, it makes sense to assume that speech sequences that are frequently used and hence form highly overlearned motor patterns are stored separately in the form of precompiled motor programs. The general notion of motor programs (Lashley, 1951; Keele, Cohen, & Ivry, 1990 for a review) as plans for muscle commands, which are prepared before a movement sequence is executed, is appealing for research in speech production because speaking is a serially ordered form of behavior. As in many other complex motor sequences, in speaking movements must be sequenced (Rosenbaum, 1991 for a review). A partial solution to this problem is the assumption of motor programs, i.e., the idea that speech movements are available in preassembled structures that control the actual articulatory movements of the production system. Once invoked, motor programs control the fast and accurate execution of a desired movement sequence. Kent, Adams, and Turner (1996) review some evidence that supports the motor program hypothesis in speech production.

If syllables are represented in the form of motor programs, one may expect syllabic effects at a very late stage of the speech production process, e.g., during articulation. The use of electromagnetic midsagittal articulography to monitor speech movements did not provide support for the hypothesis that the timing of intervocalic consonants is sensitive to their syllable affiliations. Unexpectedly, however, the stability of the articulatory timing of tautosyllabic intervocalic consonants did not differ statistically from heterosyllabic intervocalic consonants. Further experimental research on kinematic data is needed to find out whether the syllable is an articulatory motor unit.

If the mental syllabary exists, it should be theoretically possible to find differences in the activation of certain brain regions for the production of strings consisting of high- vs. low-frequency syllables. Interestingly, in a recent PET study, Hagoort, Indefrey, Brown, Herzog, Steinmetz, and Seitz (submitted) found differences in the activation of supplementory motor areas during the processing of pseudowords containing high- vs. low-frequency syllables. The authors speculate that this difference may be due to the activation of highly overused motor patterns that were needed for the production of the high-frequency syllables but not for the production of the low-frequency syllables. With the help of modern functional imaging techniques, such as PET or fMRI, it may be possible to further test the mental syllabary hypothesis.

REFERENCES

BAUMANN, M. (1995). *The production of syllables in connected speech.* Unpublished dissertation, Nijmegen University.

BOOIJ, G. (1995). *The phonology of Dutch.* Oxford: Clarendon Press.

CROMPTON, A. (1981). Syllables and segments in speech production. *Linguistics*, **19**, 663-716.

CUTLER, A. (in press). The syllable's role in the segmentation of stress languages. To appear in *Language and Cognitive Processes* (Special issue, The Sperlonga Meeting III).

FERRAND, L., SEGUI, J., & GRAINGER, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, **27**, 124-142.

HAGOORT, P., INDEFREY, P. BROWN, C., HERZOG, H., STEINMETZ, H., & SEITZ, R. (submitted). The neural circuitry involved in the reading of German words and pseudowords: A PET study.

KEELE, S. W., COHEN, A, & IVRY, R. (1990). Motor programs: Concepts and issues. In M. Jeannerod (Ed.), *Attention and Performance XIII. Motor representation and control* (pp. 77-110). Hillsdale, NJ: Erlbaum.

KENT, R. D., ADAMS, S. G., & TURNER, G. S. (1996). Models of speech production. In N. J. Lass (Ed.), *Principles of experimental phonetics* (pp. 3-45). St. Louis: Mosby.

LASHLEY, K. S. (1951). The problem of serial order in behavior. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior* (pp. 112-136). New York: Wiley.

LEVELT, W. J. M. (1989). *Speaking. From intention to articulation.* Cambridge, MA: MIT Press.

LEVELT, W. J. M., ROELOFS, A., & MEYER, A. S. (accepted). A theory of lexical access in speech production. *Behavioral and Brain Sciences.*

LEVELT, W. J. M. & WHEELDON, L. (1994). Do speakers have a mental syllabary? *Cognition*, **50**, 239-269.

MEHLER, J., DOMMERGUES, J. Y., FRAUENFELDER, U., & SEGUI, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior*, **20**, 298-305.

ROELOFS, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, **35**, 854-876.

ROSENBAUM, D. A. (1991). *Human motor control.* San Diego: Academic Press.

SUMMARY

The research reported in this thesis focuses on the role of the syllable in speech production. Levelt's model of speech production provided the general theoretical framework on which the empirical work presented in the previous chapters is based. One crucial feature of the Levelt model is that form representations are not syllabified in the mental lexicon. This assumption is based on the fact that syllable boundaries in connected speech often differ from isolated word form syllabifications. In Levelt's model, syllabification is a relatively late process in speech production. Syllables are computed during prosodification, i.e., when preselected segments, which are only specified for their serial position within morphemes but not for their syllabic position, are associated to metrical frames (see Chapter 1 for a more detailed discussion). The aim of this thesis was to look for empirical evidence for the use of syllables in the process of speech production in Dutch.

It is important to know which syllable types exist in Dutch and how frequently each of them is used in speech production. Chapter 2 contains a lexico-statistical investigation of the Dutch syllable inventory. Dutch has a great variety of syllable structures including complex onset and coda clusters. In connected speech, syllables can change their segmental make-up according to phonological sentence-level rules. To investigate the differences between citation forms and connected speech, phonological sentence-level rules were applied to a large newspaper corpus whenever a phonological string was a possible input for these rules. The output of this process can be seen as an approximation of the phonological forms in connected speech. It is shown that syllables in connected speech, i.e., *speech syllables*, tend to have more complex onsets than *lexeme syllables*, i.e., syllables that result from syllabification of citation word forms. This difference is due to the "resyllabification" of coda consonants to a following onset. One might expect these segmental alternations to lead to differences in the syllable frequencies of lexeme and speech syllables. However, in spite of the structural alternations between citation forms and connected speech it is shown that the frequencies of lexeme syllables generally represent a good estimate of the speech syllable frequencies. This finding is important for the experimental investigation of syllable frequency effects in psycholinguistics. An interesting structural finding is that despite the great diversity of syllable structure in Dutch, the vast majority of the syllables exhibits a relatively

simple syllable structure. Disregarding vowel length, the most frequent syllable structures include CV and CVC, which together account for more than 70% of all syllable tokens. Furthermore, the frequency distribution of the syllables is quite skewed. The analysis of the cumulative syllable frequencies showed that 85% of all syllables can be generated from the 500 most frequent syllables in Dutch. This finding lends some statistical plausibility to the notion of the *mental syllabary hypothesis*, according to which syllables that are often used in the speech production process are stored separately in terms of their precompiled articulatory motor programs in order to reduce the computational load during phonological encoding.

Chapter 3 reports on a syllabification study applying the metalinguistic syllable reversal task. In this task, participants first hear a bisyllabic word form and then produce its two syllables in reversed order, e.g., *filter* ('id.') → *ter-fil*. With this task the impact of certain phonological constraints of Dutch syllable structure on the syllabification behavior was investigated. In particular, we tested whether native speakers obeyed the *Branching Rhyme Constraint* (BRC), which requires syllable rhymes to minimally consist of two positions, and the *Onset Principle* (OP), according to which syllables must have an onset. For words like *letter* /lɛtər/ ('id.') the BRC and the OP can only be satisfied simultaneously if the intervocalic consonant is treated as ambisyllabic. The experimental results showed that participants generally reversed words like *letter* to *ter-let*, which supports the notion of ambisyllabicity in Dutch. When the first syllable was left open (open syllable response), as in *ter-le*, participants lengthened the final vowel in a substantial number of cases such that the BRC was still satisfied. However, in about 10% of the cases participants produced open short vowel syllables violating the BRC. The proportion of open syllable responses depended on several factors including the location of the lexical stress (there were more open syllable responses for words with final stress than for words having initial stress), the quality of the first vowel (there were more open syllable responses when the first syllable contains /ɑ/ or /ɔ/ than when it contains /ɪ/ or /ɛ/), spelling (there were fewer open syllable responses when the intervocalic consonant was spelled with two graphemes than when it is spelled with only one grapheme), and the experimental context (there were more open syllable responses when the majority of the filler items had a long vowel in the first syllable and required open syllable responses than when the majority of the fillers had a consonantal cluster and required closed syllable responses). Taken together, the results of the syllabification experiments showed that native speakers of Dutch generally obeyed the phonological constraints on syllable structure in the syllable reversal task. However, the fact that there was substantial variability in the syllabification of certain items suggests that the syllable structure of word forms is not stored in the mental lexicon but computed on-line. This interpretation is compatible with the *late-syllabification* account given in Levelt's model.

In Chapter 4 the effect of visually masked syllable primes on the naming latencies of words and pictures was investigated. Previous research in French showed that syllables might play a role at the phonological output level of speech production. If syllables are used as planning units during phonological encoding in Dutch, it should be possible to prime syllabic units and speed up the speech production process. However, in Levelt's model segments are not marked for syllable position but only for their serial positions within a word. Hence, according to the model there should be no syllable priming effect in Dutch. In the experiments, participants named words and pictures which were preceded by masked syllable primes. In the *syllable match condition* the primes corresponded to the target words' first syllable, whereas in the *syllable mismatch condition* the primes were one segment shorter or longer than the targets' first syllable. The naming of words and pictures was facilitated by the syllable primes - when compared to neutral primes - in all conditions and experiments. However, the strength of the priming effect was completely independent of the syllabic structure of prime and target, but increased with increasing segmental overlap between prime and target. This result contradicts a *syllable priming hypothesis*, but provides strong evidence for a *segmental overlap hypothesis*. This latter hypothesis is compatible with the claims about syllabification in the Levelt model, namely that syllabification is a late process.

Chapter 5 comprises the results of an articulatory study, which focused on the effects of syllable affiliation on the articulatory timing of intervocalic consonants. Electromagnetic midsagittal articulography (EMMA) was used to monitor tongue, lip, and jaw movements during the production of bisyllabic Dutch words. The articulatory timing of nominally identical intervocalic consonants that only differed in syllable affiliation was measured by computing the temporal interval between an anchor point in the first syllable (C_1) and the attainment of the articulatory target of the intervocalic consonant (C_2). The stability of the articulatory timing was expressed by the standard deviation of this interval across eight repetitions of each item. The results revealed no systematic effect of syllable affiliation.

The articulatory timing was as variable when C_1 and C_2 belong to different syllables (as was, for instance, the case for /f/ and /k/ in *fa.kir* ('id.')) as when C_1 and C_2 either belong to the same syllable (as, e.g., in *fak.tor*, ('factor')), or when the syllable affiliation of C_2 was ambiguous (as, e.g., in *fa[kk]el* ('torch')). This result does not support a *syllable timing hypothesis* according to which segments affiliated with the same syllable should be timed more stably relative to each other than segments that belong to different syllables.

Het onderzoek dat in deze dissertatie wordt gerapporteerd betreft de rol van de syllabe in spraakproductie. Het spraakproductiemodel van Levelt vormt de theoretische basis van het empirische werk in deze dissertatie. Een van de cruciale kenmerken van Levelts model is dat de syllabificatie van een woord niet is gerepresenteerd in het mentale lexicon. Deze veronderstelling is gebaseerd op het feit dat in aaneengesloten spraak de syllabe-grenzen van een woord vaak verschuiven. In Levelts model worden syllaben pas op een relatief laat moment in spraakproductie gegenereerd, namelijk tijdens het 'prosodificatieproces'. Dit houdt in dat syllaben pas worden gegenereerd wanneer de beschikbaar gekomen fonologische segmenten, die wel gespecificeerd zijn voor hun woordpositie maar niet voor hun syllabepositie, aan de metrische structuur van het woord worden gekoppeld (zie hoofdstuk 1 voor een meer gedetailleerde discussie). Het doel van deze dissertatie was evidentie te vinden voor het gebruik van syllaben in het proces van Nederlandse spraakproductie.

Om te beginnen is het belangrijk te weten welke soorten syllaben in het Nederlands voorkomen, en hoe vaak elk van hen gebruikt wordt in spraakproductie. Hoofdstuk 2 beschrijft een onderzoek naar de lexicale statistiek van de Nederlandse syllaben. Het Nederlands kent een grote verscheidenheid aan syllabe-structuren die complexe syllabe-begin en syllabe-finale consonantclusters kunnen bevatten. In aaneengesloten spraak kan de segmentele opmaak van een syllabe veranderen als gevolg van de regels van de zinsfonologie. Om de verschillen tussen woorden in hun citatievorm en in aaneengesloten spraak te onderzoeken werden de zinsfonologische regels toegepast op alle fonologische aaneenschakelingen uit een groot krantencorpus die een mogelijke input voor deze regels vormden. De uitkomst van deze procedure leverde een benadering op van de fonologische woordvormen die voorkomen in aaneengesloten spraak. Het blijkt dat de *spraaksyllaben*, dat wil zeggen, syllaben die voorkomen in aaneengesloten spraak, complexere beginconsonantclusters hebben dan *lexeemsyllaben*, dat wil zeggen, de syllaben die het resultaat zijn van de syllabificatie van woorden in hun citatievorm. Dit verschil wordt veroorzaakt door de 'hersyllabificatie' van syllabe-finale consonanten naar een volgend syllabe-begin. Men zou verwachten dat deze segmentele veranderingen leiden tot verschillen in lexeem- en spraaksyllabe-frequenties. Echter, wat werd aangetoond was dat ondanks deze structurele wisselingen de lexeemsyllabe-frequentie in het algemeen een goede schatter is voor de frequentie van de spraaksyllaben. Dit is een belangrijke bevinding voor het experimentele onderzoek naar syllabe-frequentie effecten. Een interessante structurele bevinding is dat ondanks de grote diversiteit in syllabe-structuren in het Nederlands, de meerderheid van de syllaben een relatief simpele structuur heeft. De duur van een klinker veronachtzamend bestaan de meest frequente syllabe-structuren uit CV en CVC, en vormen deze frequente syllabe-structuren meer dan 70% van alle syllabe-tokens. De verdeling van syllabe-frequenties is tamelijk scheef. Een analyse van de cumulatieve syllabe-frequenties laat zien dat in het Nederlands 85% van alle syllaben gegenereerd kan worden door de 500 meest frequente syllaben. Deze bevindingen verschaffen enige statistische plausibiliteit aan de *mental syllabary hypothesis*. Volgens deze hypothese zijn syllaben die vaak worden gebruikt in het spraakproductieproces opgeslagen als articulatorische motorprogramma's zodat er minder berekend hoeft te worden tijdens het fonologisch encoderingsproces.

Hoofdstuk 3 rapporteert een syllabificatie-studie waarin een metalinguistische syllabe-omdraaiingstaak werd toegepast. In de experimenten hoorden deelnemers een bisyllabische woordvorm. Het was hun taak om de twee syllaben in omgekeerde volgorde uit te spreken, bijvoorbeeld 'filter' moest worden uitgesproken als 'ter-fil'. Door middel van deze taak werd onderzocht wat de invloed is van bepaalde fonologische beperkingen van de Nederlandse syllabe-structuur op het syllabificatiegedrag van sprekers. Met name werd getoetst of sprekers gehoorzamen aan de *Branching Rhyme Constraint* (BRC), die vereist dat de 'rhyme' van een syllabe uit minimaal twee posities bestaat, en aan het *Onset Principle* (OP), volgens welke syllaben een 'onset' moeten hebben. Voor woorden als 'letter' kunnen de BRC en het OP alleen maar gelijktijdig nagekomen worden indien de consonant die tussen de twee vocalen in ligt als ambisyllabisch wordt behandeld. De resultaten van de experimenten lieten zien dat de deelnemers in het algemeen woorden als 'letter' omdraaiden naar 'ter-let'. Dit ondersteunt de idee dat een klanksegment ambisyllabisch kan zijn in het Nederlands. In het geval dat de eerste syllabe werd opengelaten (een 'open-syllabe-respons'), zoals bijvoorbeeld in 'ter-le', verlengden de deelnemers in een substantieel aantal gevallen de duur van de laatste klinker op zo'n wijze dat nog steeds aan de BRC werd voldaan. Echter, in ongeveer 10% van de gevallen werd de BRC geschonden doordat er een open syllabe met een korte klinker werd geproduceerd. De proportie van open-syllabe-responsen was afhankelijk van een aantal factoren. Dit waren de positie van de klemtoon in een woord (er werden meer open-syllabe-responsen gegeven bij woorden met de klemtoon op de laatste syllabe dan bij woorden met de klemtoon op de eerste syllabe), de karakteristiek van de eerste vocaal (er werden meer open-syllabe-responsen gegeven bij een /ɑ/ of een /ɔ/, dan bij een /ɪ/ of een /ɛ/ als eerste vocaal), spelling (er waren minder open-syllabe-responsen bij intervocalische consonanten die met twee grafemen werden gespeld, dan bij intervocalische consonanten die met een grafeem werden gespeld), en de experimentele context (de situatie waarin de meerderheid van de filler items een open-syllabe-respons vereisten leidde tot een groter aantal open-syllabe-responsen voor de experimentele items dan de situatie waarin de filler items voornamelijk een gesloten-syllabe-respons vereisten). Op basis van de resultaten van de syllabificatie-experimenten kon geconcludeerd worden dat sprekers van het Nederlands in het algemeen gehoorzamen aan de fonologische beperkingen van de syllabe-structuur in de syllabe-omdraaiings-taak. De aanzienlijke variabiliteit die werd waargenomen in de syllabificatie van bepaalde items suggereert echter dat de syllabe-structuur van woordvormen niet is opgeslagen in het mentale lexicon, maar *on-line* wordt gegenereerd. Deze interpretatie sluit aan bij de veronderstelling in Levelts model dat syllabificatie pas laat in het productieproces plaatsvindt.

In hoofdstuk 4 werd het effect van visueel gemaskeerde 'syllabe-primes' op de benoemingstijden van woorden en plaatjes onderzocht. Uit eerder onderzoek is gebleken dat syllaben wellicht een rol spelen op fonologisch output-niveau in spraakproductie. Als syllaben inderdaad als planningseenheden worden gebruikt tijdens het proces van fonologisch encoderen in het Nederlands, dan zou het mogelijk moeten zijn om het genereren van syllaben te versnellen door middel van het aanbieden van syllabe-primes. Echter, in Levelts model zijn fonologische segmenten niet gemarkeerd voor hun syllabe-positie, maar alleen voor hun positie in een woord. Volgens het model zouden syllabe-primes daarom geen specifiek effect mogen hebben op het genereren van syllaben in het Nederlands. Om deze hypothesen te toetsen werden tijdens de experimenten verschillende plaatjes en woorden een voor een aangeboden op een computerscherm. Aan de deelnemers werd gevraagd om de plaatjes en woorden zo snel mogelijk te benoemen. Voorafgaand aan ieder plaatje of woord verscheen een visueel gemaskeerde syllabe-prime op het computerscherm. In de *syllable match condition* correspondeerden de syllabe-primes met de eerste syllabe van het doelwoord (dat is het woord dat moest worden uitgesproken). In de *syllable mismatch condition* waren de syllabe-primes een segment korter of langer dan de eerste syllabe van het doelwoord. De resultaten lieten zien dat, vergeleken met een neutrale prime, de syllabe-primes het benoemingsproces versnelden in alle condities van alle experimenten. De mate waarin de benoemingstijd versneld werd bleek echter geheel onafhankelijk te zijn van de overeenkomst tussen de syllabe-structuur van het doelwoord en de syllabe-prime. Daarentegen lieten de resultaten wel een effect van segmentele overlap zien: het versnellingseffect werd groter naarmate er meer segmentele overlap was tussen syllabe-prime en doelwoord. Deze uitkomst is in tegenspraak met een *syllable priming hypothesis*, maar ondersteunt zeer duidelijk een *segmental overlap hypothesis*. Deze laatste hypothese stemt overeen met de veronderstelling in het Levelt model dat syllaben pas laat in het productieproces worden gegenereerd.

Hoofdstuk 5 beschrijft de resultaten van een articulatorische studie naar de effecten van syllabe-toekenning op de timing van de articulatie van intervocalische-consonanten. *Electromagnetic midsagittal articulography* (EMMA) werd gebruikt om de bewegingen van de tong, lippen, en kaak te volgen tijdens de productie van bisyllabische Nederlandse woorden. De kritische meting betrof het tijdsinterval tussen een referentiepunt in de eerste syllabe (C_1) en het bereiken van het articulatorische doel van de intervocalische-consonant (C_2). Dit interval werd gebruikt om de timing van de articulatie van nominaal dezelfde intervocalische-consonanten te meten, die alleen verschilden in hun toekenning aan de eerste of tweede syllabe. De standaardafwijking van dit tijdsinterval, berekend over acht herhalingen van ieder item, werd gebruikt om de stabiliteit van de timing van de articulatie uit te drukken. De resultaten lieten geen systematisch effect van syllabe-toekenning zien. De timing van de articulatie was net zo variabel in de conditie waarin C_1 en C_2 tot verschillende syllaben behoorden (zoals bijvoorbeeld de /f/ en de /k/ in *fa.kir)*, als in de conditie waarin C_1 en C_2 allebei tot dezelfde syllabe behoorden (zoals bijvoorbeeld de /f/ en /k/ in *fak.tor*), of wanneer de syllabe toekenning van C_2 ambigue was (zoals bijvoorbeeld de /k/ in *fa[kk]el*). Dit resultaat is in tegenspraak met een *syllable timing hypothesis*. Volgens deze hypothese zou de timing tussen twee segmenten die aan dezelfde syllabe toegekend zijn meer stabiel moeten zijn dan de timing tussen twee segmenten die tot verschillende syllaben behoren.

CURRICULUM VITAE

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