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Brief article

The minimal unit of phonological encoding: prosodic or lexical word

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Abstract

Wheeldon and Lahiri (*Journal of Memory and Language 37* (1997) 356) used a prepared speech production task (Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: comparisons of speech and typewriting. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 117–152). New York: Academic Press; Sternberg, S., Wright, C. E., Knoll, R. L., & Monsell, S. (1980). Motor programs in rapid speech: additional evidence. In R. A. Cole (Ed.), *The perception and production of fluent speech* (pp. 507–534). Hillsdale, NJ: Erlbaum) to demonstrate that the latency to articulate a sentence is a function of the number of phonological words it comprises. Latencies for the sentence [Ik zoek het] [water] 'I seek the water' were shorter than latencies for sentences like [Ik zoek] [vers] [water] 'I seek fresh water'. We extend this research by examining the prepared production of utterances containing phonological words that are less than a lexical word in length. Dutch compounds (e.g. *ooglid* 'eyelid') form a single morphosyntactic word and a phonological word, which in turn includes two phonological words. We compare their prepared production latencies to those syntactic phrases consisting of an adjective and a noun (e.g. *oud lid* 'old member') which comprise two morphosyntactic and two phonological words, and to morphologically simple words (e.g. *orgel* 'organ') which comprise one morphosyntactic and one phonological word. Our findings demonstrate that the effect is limited to phrasal level phonological words, suggesting that production models need to make a distinction between lexical and phrasal phonology. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Speech production; Prosody; Phonological words

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1. Introduction

In this article we focus on the scope of processing during phonological encoding. Levelt (1989, 1992) argued that the unit of phonological encoding is the phonological word (ω) – a prosodic unit comprising minimally a stressed foot and maximally a single lexical word combined with any associated unstressed function words (Booij, 1995; Gussenhoven, 1983, 1993; Lahiri, Jongman, & Sereno, 1990; see Wheeldon, 2000 for a review). Levelt claims that once words are selected for production their phonological representations are combined to form phonological word frames. The phonological segments for each word are made available separately and then associated to the newly constructed phonological word frames in a left to right manner. For example, in the utterance *I ate an apple* the four lexical items can resyllabify and cliticize to form two phonological words (1a) or even just a single phonological word with one main lexical stress (1b).

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                 x
         x       x
a.   [[aɪ·ɛt·n̩]ω [æ·pl̩]ω ]
                                        (1)
              x
              x
b.   [[aᴵɛ·tᵊ·næ·pl̩]ω ]
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As the segments for each syllable are associated to their prosodic frame they are used to retrieve stored, syllable-sized, articulatory routines (Levelt, Roelofs, & Meyer, 1999; Levelt & Wheeldon, 1994). When the articulatory routines for the entire phonological word have been retrieved, the phonetic plan can be articulated. Thus, during the production of connected speech, a whole phonological word is constructed before articulation commences and syllable structure is determined on the fly within phonological word boundaries.

A limited amount of relevant experimental data exists. A number of experimental findings suggest that all the syllables of a word are encoded prior to the onset of articulation. Meyer and Schriefers (1991) demonstrated significant priming effects from spoken distractors that overlapped with either the first or the second syllable of the target picture names in a picture–word interference task (but see Schriefers & Teruel, 1999). Also the time taken to initiate production of a word has been shown to increase with the number of syllables it contains (Eriksen, Pollack, & Montague, 1970; Klapp, 1974; Klapp, Anderson, & Berrian, 1973; but see Bachoud-Levi, Dupoux, Cohen, & Mehler, 1998). However, such experiments do not distinguish between phonological and morphosyntactic words as the minimal unit of phonological encoding. A morphosyntactic word (m) can be a single morpheme (e.g. *heat*) or a prefixed word (e.g. *reheat*) or even two attached stems as in the case of compounds (e.g. *heatwave*). Crucially, morphosyntactic words comprise units that are attached in the lexicon rather than attached on-line as in the case of phonological words and are treated as single units by syntactic and morphological rules.

Wheeldon and Lahiri (1997) used a prepared speech production technique to examine phonological word production. Earlier research with a similar technique demonstrated that the latency to produce a prepared list of words increases linearly with list length, that is, the longer the list the longer it takes you to begin to say it (Sternberg, Monsell, Knoll, & Wright, 1978; Sternberg, Wright, Knoll, & Monsell, 1980). Interestingly, the addition of unstressed words into a list does not alter the slope of the latency function. In other words, the slope for the list BAY RUM MARK is the same as the slope for the list BAY AND RUM AND MARK. Sternberg et al. concluded that production latency in their task was a function not of the number of words in a list but of the number of stress groups. Wheeldon and Lahiri (1997) proposed that the Sternberg et al. 'stress group' is in fact a phonological word. They therefore looked for an effect on prepared sentence production latencies of the number of phonological words it comprises when number of syllables, morphosyntactic words and syntactic structure are held constant. The experiments were conducted in Dutch and made use of the processes of cliticization. They tested the production of phonological words comprising a morphosyntactic word plus unstressed function words. The experiment tested the delayed production of the three sentence types shown in (2).

a	Ik [zoek het] [water]	'I seek the water'	
b	Ik [zoek] [vers] [water]	'I seek fresh water'	(2)
c	Ik [zoek] [water]	'I seek water'	

Sentence types (2a) and (2b) have the same number of morphosyntactic words and syllables, and share syntactic structure. They differ, however, in their number of phonological words. In (2a) the word *het* is destressed and cliticizes to the verb becoming a single phonological word. In contrast, in (2b) *vers* is stressed and forms an independent phonological word. All sentences were elicited from subjects using a question answer technique. Subjects read a noun phrase (e.g. *vers water* 'fresh water') and then heard a question (e.g. '*Wat zoek je?*' 'What do you seek?'). They then had approximately 4 s to fully prepare their response, which they produced on cue. The latency to produce the clitic sentences like (2a) was 14 ms faster than the latency to produce the nonclitic sentences like (2b) and (2c) which did not differ. Crucially, this effect could not be attributed to the greater conceptual complexity of the nonclitic sentences which comprised an additional content word (e.g. *vers*). We tested the production of pronoun sentences in which the noun phrase consisted simply of the pronoun *het* (e.g. *Ik zoek het* 'I seek it'). This pronoun is phonologically identical to the neutral Dutch article. However, in the pronoun sentences, *het* is phrase final and receives stress thereby becoming a phonological word in its own right. The pronoun sentences thus comprise the same number of phonological words as the clitic (2a) sentences but have a different number of content words. Pronoun and clitic sentences yielded identical naming latencies. Thus, prepared sentence production latencies proved to be a function of the number of phonological words in the utterance.

The experiment we report was designed to test the Levelt (1989) claim that the phonological word rather than the morphosyntactic word is the *minimal* unit of phonological encoding. According to Levelt (1989), phonological encoding is only sensitive to phonological word boundaries – lexical word boundaries are lost during the computation, allowing syllabification to occur across word boundaries. We can test Levelt's claim by examining the prepared production of utterances containing phonological words that are less than a morphosyntactic word in length. According to Levelt, prosodic words which are smaller than morphosyntactic words should behave in exactly the same way as prosodic words which are the same size or larger than morphosyntactic words. All phonological words in the Wheeldon and Lahiri (1997) experiments were either the same size as, or larger than, a morphosyntactic word. The experiment we report here uses a similar task to test whether morphosyntactic-word-internal phonological words behave similarly to the phrasal level phonological words tested by Wheeldon and Lahiri (1997).

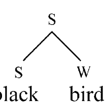
2. The experiment

Compounds constitute an interesting conflict between morphosyntactic and phonological words. A compound like *bláckbird* is a single morphosyntactic word (in contrast to the adjectival phrase *black bird*), because it acts as a single morphological element with a single head. A morphosyntactic word is inflected only once and the inflection is usually carried by the head, which in this nominal compound is *bird*. The compound inflects for number and case as a single element: *blackbirds* PLURAL, *the blackbird's nest* GENITIVE. The nonhead *black* cannot bear any other suffix as for instance a comparative: **blackerbird*. This would be interpreted as if *black* was a real adjective referring to a bird that was blacker than normal.[1] Neither can the adjectival element in the compound be modified **a rather/very BLACKbird*.

With regard to prosodic structure, compounds behave on the one hand like two phonological words, but on the other as a single phonological unit. Since all morphosyntactic words are phonological words, both *black* and *bird* are phonological words [bláck][bírd] each with their own word stress. Nevertheless, the compound behaves like a single phonological unit with a single main stress and a secondary stress: *bláckbírd* (Nespor & Vogel, 1986, p. 112). What is the status of this unit? Descriptively it is a 'super-word' and one way of capturing this is to assume that phonological word formation is recursive: $\{[[\text{black}]_\omega[\text{bird}]_\omega]_{m/\omega}\}_{\text{noun}}$[2] (cf. Booij, 1995, p. 144) or a regular phonological word (Nespor & Vogel, 1986, pp. 110–118). Further support that compounds are closer to a phonological word than a phrase comes from the domain of phonological rules. For example, in Dutch, progressive assimilation which devoices a fricative after a voiceless obstruent applies obligatorily within prosodic words and compounds, but is optional within larger domains like phonological phrases (Booij, 1995, p. 59). Such rules can vary within dialects, but it is certainly the case that there is a much higher likelihood of the domain of a regular phonological word and a compound to be closer than that of a phonological phrase. Is this 'super-word' unit the same as a cliticized phonological word – the answer is no since the internal phonological brackets are maintained. Thus, for example in Dutch, there is no resyllabification within a compound like *bloedonderzoek* 'blood

[1] In some special instances in noun–noun compounds, the first noun can bear inflection as in *menfolk*.

[2] Another way of capturing the same fact is by Chomsky-adjunction (see Booij, 1995, p. 145).



research', and the [d] of *bloed* does not become the onset of the next syllable, and therefore is voiceless because it is at the end of a phonological word.[3] In contrast, in the phrase *man en vrouw* 'man and wife', within the cliticized phonological word *manen*, the syllabification would be [ma.nen].

The question we ask is the following: for the purposes of phonological encoding, are compounds treated as one phonological word or two? In what follows, we assume that the compound undergoes recursive phonological word formation. The experiment we report therefore examined the delayed production of utterances containing compounds, adjectival phrases and monomorphemic words. Examples of the materials are given in (3). The compounds in (3a) are noun–noun compounds. As mentioned above, they form a single morphosyntactic word, but a single phonological word made up of two phonological words. The main stress on these compounds is word initial. The words in (3b) form an adjectival phrase consisting of two phonological and morphological words. Within the phrase, the main stress goes on the second word. In (3c) and (3d) we have monomorphemic words which are single phonological words. As compounds have word initial stress whereas main stress in the adjective–noun phrases normally falls on the noun, two sets of morphologically simple words were included to test for any effect of stress pattern on production latencies. The words in (3c) are stressed on the first syllable, and those in (3d) on the second syllable.

a. COMPOUND	*ooglid* 'eyelid'	x x x $\{[[\text{oog}]_{\omega}[\text{lid}]_{\omega}]_{M/\omega}\}_{NOUN}$	
b. PHRASE	*oud lid* 'old member'	x x x $\{\{[\text{oud}]_{M/\omega}\}_{ADJ}\{[\text{lid}]_{M/\omega}\}_{NOUN}\}_{PHRASE}$	(3)
c. MONOMORPHEMIC INITIAL STRESS	*orgel* 'organ'	x $\{[\text{orgel}]_{M/\omega}\}_{NOUN}$	
d. MONOMORPHEMIC FINAL STRESS	*orkaan* 'hurricane'	x $\{[\text{orkaan}]_{M/\omega}\}_{NOUN}$	

The issue here is whether compounds are treated as one or two phonological words as the minimal unit for purposes of phonological encoding. The question of interest is whether, in our prepared pronunciation task, compounds (e.g. *ooglid*) behave like adjective–noun phrases (e.g. *oud lid*) which comprise two lexical and two phonological words or like morphologically simple words (e.g. *orgel/orkaan*) which comprise one morphosyntactic and one phonological word.

[3] There is controversy regarding the domain of final devoicing in Dutch. We follow Booij in assuming that final devoicing is a word based process and not syllable based (cf. Booij, 1985, 1995, p. 174).

3. Method

3.1. Vocabulary

The experimental vocabulary contained four sets of 12 items: noun–noun compounds, adjective–noun phrases, and two sets of morphologically simple words, one set stressed on their initial syllable and the other set on their final syllable (see Appendix A). The second morpheme of each compound also appeared in an adjective–noun phrase. Onset phonemes across the three groups were matched as closely as possible sharing at least voicing and manner of articulation. Compounds and morphologically simple words were also matched for word frequency (see Appendix A). Forty-eight filler words were also chosen; half had initial stress and half had final stress.

3.2. Design and procedure

The experiment consisted of nine blocks of 32 trials. Each experimental word occurred once within a three block set, four from each condition occurring at each of three preparation latencies. The rest of the trials were filler trials. Within a block set, words were pseudo-randomly assigned to trial positions with the constraint that words from the same condition never occurred on consecutive trials. The assignment of words to preparation latencies was rotated across block sets and the order of presentation of the three block sets was rotated across participants.

Events on each trial were as follows. First, a fixation cross appeared centred on the screen for 500 ms. Then 500 ms after the offset of the fixation cross the word to be produced appeared centred on the screen for 500 ms. This was followed by a series of three beeps. The first occurred 2 s after the offset of the word and the second occurred 1 s later. In order to prevent participants from anticipating the final beep, the third and last beep had a variable latency measured from the offset of the second beep. Three latencies were used: 750, 1000, or 1250 ms. Each verb in each condition occurred once at each of the three latencies. There was a 2 s pause between trials. Participants' response latencies and durations were measured and their responses were recorded onto tape.

Participants were tested individually in a soundproof booth. They were seated in front of a window through which they could see a computer screen and wore headphones through which they heard the experimental questions. Participants were told that on each trial they would see either a word or a phrase on the screen. They were asked to respond with an utterance beginning *het was* 'it was' and continuing with what they had just read. They were told that they would have approximately 4 s to prepare their response as fully as possible and were asked to speak naturally. All participants then completed six practice trials during which they first saw a practice trial and heard a recorded example response. They completed the same trial immediately after. Participants were allowed short breaks between blocks.

3.3. Apparatus

Participants' responses were recorded by a Sony DTC55 ES DATrecorder. An analogue voice-key registered voice onset and offset times during sentence production. The experiment was controlled by a Hermac PC.

3.4. Participants

Eighteen participants were tested. They were all native Dutch speakers who were members of the Max Planck subject pool. They were paid for their participation.

3.5. Results

The analyses we report are based on data from correct response trials, following some exclusions intended to reduce the noise in the data. All data points beyond two standard deviations from the mean were counted as outliers and were removed. Incorrect responses were also removed from the latency data. This resulted in the loss of only 4.8% of the data. A response was marked as an error when the subject produced an utterance that differed from the intended utterance or when the subject produced the intended sentence with any disfluency. Correct responses that were produced before the final beep were also excluded. Missing values were substituted by a weighted mean based on subject and item statistics calculated following Winer (1971, p. 488).

Mean naming latencies are given in Table 1. Production latencies for the adjective–noun phrases were approximately 12 ms longer than latencies for all other sentence types. Analysis of variance yielded a significant main effect of sentence type ($F_1(3,51) = 7.8$, $P < 0.001$; $F_2(3,44) = 3.7$, $P < 0.05$). Newman–Keuls pairwise comparisons yielded a number of significant differences. Adjective–noun phrases were significantly slower than compounds in both the subject ($P < 0.01$) and item ($P < 0.01$) analyses. Adjective–noun phrases were also significantly slower than initial-stressed simple words ($P < 0.01$, by subjects; $P < 0.05$, by items). The difference between the adjective–noun phrases and the final-stressed simple words just failed to reach significance by items ($P < 0.01$, by subjects; $P > 0.05$, by items). No other differences approached significance.

Sentence durations are also given in Table 1. There was a highly significant main effect of sentence type ($F_1(3,51) = 54.4$, $P < 0.001$; $F_2(3,44) = 14.7$, $P < 0.001$). Newman–Keuls pairwise comparisons showed that all conditions differed significantly from each other ($P < 0.001$). Error rates were small and a similar analysis yielded no significant effects.

Table 1
Mean production latencies and durations in ms and percentage error rates for sentences in the three experimental conditions

Condition		Latency	Duration	% error
(1) Compound	*ooglid*	349	700	3.0
(2) Adjective–noun	*oud lid*	360	732	2.0
(3) Simple-initial	*orgel*	348	637	3.0
(4) Simple-final	*orkȃan*	351	678	2.0

Table 2
A hypothetical stimulus set of phrases varying in their number of morphosyntactic and phonological words[a]

	Morphosyntactic words	Phonological words	Relative prepared latency
(i) [saw the] [birds]	3	2	Fast
(ii) [saw] [birds]	2	2	Fast
(iii) [saw] [black] [birds]	3	3	Slow
(iv) [saw] [blackbirds$_{\text{COMPOUND}}$]	2	3 > 2	Fast

[a] The relative latencies are derived from the above experiment and the findings of Wheeldon and Lahiri (1997).

4. Discussion

This experiment yielded a very strong pattern of results. The production latency for compounds clearly patterned with the production latencies for morphologically simple words rather than with the adjective–noun phrases. The size of effect is similar to that observed by Wheeldon and Lahiri (1997). However, the production latencies for this experiment are best described as a function of morphosyntactic word boundaries rather than purely prosodic word boundaries. This finding appears to contradict the conclusion drawn from the results of Wheeldon and Lahiri (1997), that the phonological word is the unit of encoding in the later stages of speech production. To relate our earlier findings with the present one, we use a hypothetical set of stimuli comparing the crucial conditions. These stimuli are shown in Table 2.

Clearly a strict morphosyntactic account is not viable in explaining the results. If this had been so, then conditions (i) and (iii) should have given the same result. The only possible explanation is that the prosodic word status that counts for the encoding is at the level of phrasal prosodic structure and that the processes that compute phrasal prosody are blind to word internal structure. In linguistics, a distinction is made between lexical phonological processes which interact with word formation, and postlexical phonological processes which operate on the phrasal level (Kiparsky, 1982; Mohanan, 1986).[4] It is possible, therefore, that the prepared speech production test is sensitive only to phrasal level units. As a result, the internal structure of the compound plays no role for phonological encoding, and counts as a single phonological word. It may, of course, play a role for other purposes.

This experiment also demonstrated that a unit described purely in terms of stressed and destressed syllables is inadequate. Although compounds have main stress on their first syllable the second syllable carries secondary stress. Nevertheless compound production latencies are indistinguishable from those of morphologically simple words with destressed second syllables. The differing stress patterns of the morphologically simple words also had no significant effect on production latencies. The pattern of results for naming latencies is also clearly independent of the spoken duration of the utterances. Latencies for utterances containing initial and final stressed words did not differ despite

[4] Hayes argues for certain phrasal phenomena which may be precompiled in the lexicon where precompiled rules precede rules of lexical phonology. The postlexical level referred to here is the true phrasal level (Hayes, 1990, p. 107).

large and significant differences in spoken duration. We conclude, therefore, that the minimal unit of phonological encoding is the phonological word at the phrasal level. Our experiments only focused on two-word compounds. If the compounds are longer, it is possible that the unit chosen may differ for different utterances (e.g. sentence length) and in different speaking contexts, or that the compound is broken up into more phonological words for rhythmic reasons (Dresher, 1994; Ghini, 1993). For example, compounds like *psychology masters application forms* could have the structures shown in (4):

a. ([[psychology] [masters] [application] [forms]])
b. ([[psychology] [masters]] [[application] [forms]]) (4)

Both compounds would consist of a single morphosyntactic word and in all probability would be broken up into two phonological words for the purposes of encoding. Finally, there remains the issue of cross-linguistic differences in the scope across which dependencies may operate during the generation of prosodic structure. Lahiri (2000) discusses several tonal and intonation processes in languages that require a processing scope greater than a phonological word.

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Appendix A

Words and frequency counts for the four experimental conditions are shown in the following table. English translations are given in parentheses.

Compounds		Adjective–noun phrase	Simple initial stress		Simple final stress	
*dag*blad (magazine)	19	dun *boek* (thin book)	*bood*schap (message)	66	bar*baar* (barbarian)	5
*dag*licht (daylight)	12	dun *plan* (thin plan)	*blik*sem (lightning)	13	bor*deel* (brothel)	9
*dag*boek (diary)	24	dun *haar* (thin hair)	*bor*stel (brush)	5	ba*nier* (banner)	1
*grond*plan (groundplan)	2	geel *veld* (yellow field)	*gem*ber (ginger)	2	gi*gant* (giant)	1
*grond*recht (groundrights)	3	geel *vlak* (yellow surface)	*gei*ser (geyser)	1	gor*dijn* (curtain)	45

(*continued*)

Compounds		**Adjective–noun phrase**	**Simple initial stress**		**Simple final stress**	
*grond*vlak (surface)	1	geel *blad* (yellow leaf)	*gor*del (girdle)	8	gra*naat* (granate)	8
*vlieg*tuig (aeroplane)	52	fel *tuig* (bright harness)	*var*ken (pig)	23	for*nuis* (stove)	5
*vlieg*veld (airport)	20	fel *licht* (bright light)	*vlin*der (butterfly)	10	fram*boos* (raspberry)	2
*vlieg*werk (flightwork)	1	fel *wit* (bright white)	*ves*per (vesper)	2	flu*weel* (velvet)	5
*oog*haar (eyelash)	1	oud *recht* (old right)	*ok*sel (armpit)	9	or*kest* (orchestra)	11
*oog*lid (eyelid)	14	oud *werk* (old work)	*or*gie (orgie)	3	or*gaan* (organ)	46
*oog*wit (eyewhite)	1	oud *lid* (old member)	*or*gel (organ)	7	or*kaan* (hurricane)	4
Mean	12.5			12.4		11.8
SD	2.0			2.1		2.0

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