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Serial Order in Planning the Production of Successive Morphemes of a Word

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Five implicit priming experiments examined whether the speech production system can plan noninitial morphemes of a word in advance of initial ones. On each trial, subjects had to produce one word out of a set of three words as quickly as possible. In a homogeneous condition, the responses shared part of their form, whereas in a heterogeneous condition they did not. The first experiment shows that the task is sensitive to morphological planning. In producing disyllabic simple and compound nouns, a larger facilitatory effect was obtained when a shared initial syllable constituted a morpheme than when it did not. The next three experiments suggest that successive morphemes are planned in serial order. In producing nominal compounds, no facilitation was obtained for noninitial morphemes. In producing prefixed verbs, facilitation was obtained for the prefix but not for the noninitial base. Sharing morphemes often implies semantic overlap. The fifth experiment shows that semantic similarity per se yields inhibition rather than facilitation. Computer simulations show that the WEAVER model of word-form encoding (Roelofs, 1992b, 1994, submitted-a) accounts for the findings.

Speech production requires advance planning. This raises the question of what the planning units are and which constraints hold for the planning process (e.g., Lashley, 1951; Jordan & Rosenbaum, 1989). For example, what are the degrees of freedom in planning polymorphemic words? Issues of advance planning and lexical representation are related. Two major views in the psycholinguistic research on morphological complexity are the full listing hypothesis and the decomposition hypothesis (Butterworth, 1983). According to the full listing hypothesis, the lexical representations of polymorphemic forms are morphologically unanalyzed, whereas according to the decomposition hypothesis, they are analyzed in their constituent morphemes. If morphemes are not stored with words in memory, they cannot be used in production. Thus, only decomposed form entries allow morphemes to be planning units. In a decomposition view, the morphemes of a word may be planned serially or in parallel.

This paper addresses the question of whether the speech production system can plan noninitial morphemes of a word before initial ones. Evidence from speech errors suggests that prefixed words such as *disappear* and *reappear* are assembled out of their morphemes during production (e.g., Dell, 1986; Stemberger, 1985a). No evidence exists, however, that bears on the question of whether it is possible to plan the morpheme *appear* in advance if it is known beforehand that either the word *disappear* or the word *reappear* has to be produced. The current paper provides evidence that successive morphemes of a word have to be planned one after another. Preparation of noninitial morphemes of a word before initial ones is not possible, even when these noninitial morphemes correspond to the forms of fully fledged words.

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The work reported in this paper deals with lexical access in speech production, in particular, the second stage of the access process involving the encoding of word forms (the first stage is lemma retrieval and will not be addressed). Theories conceive of word-form encoding (e.g., Dell, 1986, 1988; Levelt, 1989, 1992) as the mapping of a representation of the word as a semantic–syntactic entity (the word's lemma) onto an articulatory program (phonetic plan). This is achieved by recovering the word's morphemes and phonemic segments from memory and serially grouping the segments into phonological syllables. These syllables are used to derive the articulatory program. The phonological syllables created during the encoding process together make up phonological words (e.g., Levelt, 1989, 1992; Levelt & Wheeldon, 1994). Phonological words correspond to domains of syllabification and of stress assignment and are domains for the application of phonological rules (e.g., Booij, 1983, 1995; McCarthy & Prince, 1990, 1993). Phonological words may be smaller than lexical words (e.g., *appear* in *disappear*) or larger (e.g., the cliticized form *appearin* combining the verb *appear* and the preposition *in*).

Theories of the encoding of word forms often assume that a word is planned in a rightward incremental fashion (e.g., Dell, 1986, 1988; Kempen & Hoenkamp, 1987; Levelt, 1989, 1992). Incremental planning means that an encoding stage is initiated by a critical fragment of the output of a preceding stage rather than its complete output. That is, a process starts working on the basis of partial input. For example, syllabification starts when it receives the initial segments of a word. The process does not have to wait until all the segments of the word have been made available. A central assumption of these theories is that processing proceeds in a ''rightward'' fashion, that is, from the beginning of a word to its end (i.e., Dell, 1988; Levelt, 1989, 1992).

The assumption of rightward incrementality is supported by a variety of empirical findings about the encoding of monomorphemic words, both monosyllabic and polysyllabic (i.e., Meyer, 1990, 1991). However, whether seriality holds for the encoding of morphemes of polymorphemic words is unknown. In general, whereas morphological complexity has received much attention in the study of language comprehension (e.g., Henderson, 1985; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Schriefers, Zwitserlood, & Roelofs, 1991) and language acquisition (especially inflectional morphology, e.g., Pinker & Prince, 1988), it has been largely ignored in the study of language production. The comprehension bias in psycholinguistics may be due to a lack of appropriate experimental techniques for production research (cf. Meyer, 1992). I will argue that it is important to study morphology in speech production. Furthermore, it will become clear from the research reported here that available techniques are sensitive to morphological structure in production.

It is important to examine whether seriality holds for polymorphemic words, because it seems plausible that left-to-right encoding does not hold for morphemes. Morphemes often constitute fully fledged phonological words of their own. This means that information about the form of these morphemes is, to a large extent, independent of the information about other morphemes in the word (e.g., Goldsmith, 1990; Spencer, 1991). Thus, it seems plausible that they function as independent planning units as far as serial order is concerned.

The paper is organized as follows. First, to set the theoretical scene, I briefly describe the WEAVER model of word-form encoding in speech production (Roelofs, 1992b, 1994, submitted-a). WEAVER (Word-form Encoding by Activation and VERification) is a computer model developed within the theoretical framework for speech production advanced by Levelt and colleagues (e.g., Levelt, 1989, 1992; Levelt & Wheeldon, 1994). The model shares much in common with other approaches (e.g., Dell, 1986, 1988). WEAVER is taken as the theoretical framework for the current paper because it is more explicit than other approaches about the particular issues addressed. Second, I describe the experimental paradigm used: the implicit priming paradigm developed by Meyer (1990, 1991). Third, I report the results of five experiments testing the model. Finally, I will show by computer simulation that WEAVER accounts for the findings. The paper ends with a general discussion addressing a number of empirical and theoretical issues raised by the experiments.

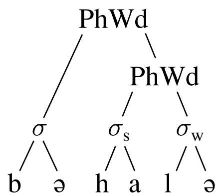
Theoretical Framework

Following Levelt and colleagues, Weaver conceives of lexical access in speech production as a process consisting of two major steps, called lemma retrieval and word-form encoding (cf. Dell, 1986). In conceptually driven lemma retrieval, a lexical concept is used to recover the lemma of the corresponding word from memory. A lemma is a memory representation of the syntactic properties of a word. For example, a verb lemma says that the word is a verb and makes explicit the word's argument structure. A verb lemma also contains a number of abstract morphosyntactic slots for the specification of tense and agreement parameters and for the specification of mood (e.g., indicative, imperative). Setting these parameters provides an index to a form pointer. The lemma retrieval process delivers this pointer to the processes that recover the word's morphophonological properties from the mental lexicon and that encode the form of the word. The memory representation of these form properties is sometimes called the word's lexeme (e.g., Kempen & Huijbers, 1983).

Assume a Dutch speaker wants to verbalize the concept TO OBTAIN. First, the ''lemma retriever'' takes the lexical concept and makes available the lemma information of the word *behalen* (for a theory and computer model of lemma retrieval, see Roelofs, 1992a, 1992b, 1993). That is, the process delivers the syntactic property verb, slots for the word's mood, tense, and agreement values, and a form pointer. To encode the appropriate word form, for example, the infinitival form [bə.ha.lə] instead of the imperatival form [bə.hal], the mood parameter has to be set. The lemma and its diacritic features are input to word-form encoding. The articulatory program is derived in three major steps: morphological encoding, phonological encoding, and phonetic encoding (Levelt, 1989). The ''morphological encoder'' takes the lemma of *behalen* plus its diacritics, and outputs, respectively, the prefix, root, and plural suffix morphemes

⟨be⟩, ⟨haal⟩, and ⟨en⟩.

This process thus concerns what is traditionally called the ''syntax-morphology interface'' (e.g., Spencer, 1991). The ''phonological encoder'' successively takes ⟨be⟩, ⟨haal⟩, and ⟨en⟩ and produces the phonological word (skipping the foot level)



That is, the process delivers a syllabified sequence of segments, together with a stress pattern over the syllables (σ), where *s* and *w* stands for metrically strong and weak (cf. Liberman & Prince, 1977). This representation says that the infinitival form of *behalen* constitutes a phonological word (PhWd) comprising a syllable corresponding to the prefix and an embedded phonological word corresponding to the base (cf. Booij, 1983, 1995; McCarthy & Prince, 1990, 1993).[1] The prefix syllable has /b/ as onset and /ə/ as nucleus. The embedded phonological word consists of two syllables. The first syllable has /h/ as onset and /a/ as nucleus, and the second syllable has /l/ as onset and /ə/ as nucleus. The process that

[1] I assume that recursion of PhWd is possible. Foot and syllable theories, however, exclude recursion of the categories Ft and σ (for arguments and references, see Booij, 1983, 1995; McCarthy & Prince, 1993).

generates this phonological word representation thus comprises what is traditionally called the ''morphology-phonology interface'' (e.g., Goldsmith, 1990).

Dutch prefixes such as ⟨be⟩, ⟨ver⟩, and ⟨ont⟩ are independent syllabification domains, but they are not phonological words of their own (Booij, 1995). For example, the segment /r/ of ⟨ver⟩ in the verb *verachten* (*despise*) is not syllabified with the base verb *achten*, as the Maximal Onset Principle (e.g., Goldsmith, 1990) would predict, but is made the coda of ⟨ver⟩. This does not hold for the string *vera* in a simple word such as *veranda* (*verandah*), which is syllabified as $(\text{və})_\sigma(\text{rɑn})_\sigma(\text{dɑ})_\sigma$. Thus, in models that assume that syllabifications are computed rather than stored (e.g., Levelt, 1992; Roelofs, 1992b, 1994, submitted-a), the syllabification process has to ''know'' the morphemic source of the segments that it receives. The process cannot blindly accept a string of segments and syllabify the segments without taking morpheme boundaries into account. This implies that the lexical entries of words have to indicate morpheme boundaries. The prefixes mentioned above are, however, not phonological words of their own. A phonological word must contain at least one stressable syllable (phonological words correspond to domains of stress assignment), but ⟨ver⟩ and ⟨be⟩ do not. Because prefix syllables are metrically dependent on a host, they have to be adjoined to the phonological word corresponding to the base verb. For example, the syllable $(\text{bə})_\sigma$ realizing the prefix ⟨be⟩ of *behalen* is adjoined to the disyllabic phonological word $((\text{ha})_\sigma(\text{lə})_\sigma)_{\text{PhWd}}$, creating the trisyllabic phonological word $((\text{bə})_\sigma((\text{ha})_\sigma(\text{lə})_\sigma)_{\text{PhWd}})_{\text{PhWd}}$.

Finally, the ''phonetic encoder'' takes the phonological word representation delivered by the phonological encoder and produces the articulatory program,

[bə]['ha][lə].

According to Levelt (1989, 1992; Levelt & Wheeldon, 1994), this representation describes *behalen* in terms of the syllable programs [bə], [ha], and [lə], which are recovered from a phonetic syllabary. The articulatory program makes explicit the gestural scores for the articulatory movements and indicates, among other things, that the second syllable should be pronounced louder or longer than the other syllables. This encoding stage thus includes what is sometimes called the ''postlexical phonology'' (e.g., Goldsmith, 1990).

The WEAVER model (Roelofs, 1994, submitted-a) computationally implements the encoding processes just described. WEAVER integrates a spreading-activation based network with a parallel object-oriented production system. The type of system is a mix of traditional AI, connectionism, and traditional cognitive modeling (cf. Anderson, 1983). The model conceives of the word-form lexicon as a network of morphophonological nodes and labeled links. The network is accessed by spreading of activation. Activation of nodes triggers procedures that build incrementally a phonetic plan. An important task of these procedures is to verify the link between an activated node and the selected nodes one level up in the network. Morphological procedures select the morpheme nodes that appropriately encode a selected lemma and its tense, agreement, and mood parameters. Phonological procedures select the phonemic segments of the morphemes and syllabify the segments in order to construct phonological syllables as constituents of phonological word representations. Finally, phonetic procedures select the articulatory programs that appropriately encode these phonological syllables.

Elsewhere (Roelofs, 1994, submitted-a), I have shown by computer simulation that the WEAVER model accounts for key empirical findings about the time course of phonological facilitation and inhibition from spoken distractors in picture naming (Meyer & Schriefers, 1991), for effects from the order of encoding inside and between the syllables of a word (Meyer, 1990, 1991), for effects from word and syllable frequency (Jescheniak & Levelt, 1994; Levelt & Wheeldon, 1994), and for classical speech errors (Nooteboom, 1969). Furthermore, novel predictions concerning word and sentence production have been tested and validated in new experiments (Roelofs, submitted-a, submitted-b).

An important aspect of the model for the present paper is that the encoding algorithm provides for a suspension-resumption mechanism that supports (rightward) incremental generation of phonetic plans. The three processing stages (i.e., morphological encoding, phonological encoding, and phonetic encoding) compute aspects of a word form in parallel from the beginning of the word to its end. When a stage has used the available information before reaching the end of the word, it stops and waits until it gets new input. When further information is provided, the stage continues from where it stopped.

Evidence for Morphological Structure in Lexical Entries

The literature about the morphological processes and structures underlying speech production is scarce. The existing empirical evidence mainly comes from two sources: speech errors in normal and aphasic speakers and production latencies obtained in word pronounciation tasks. The present discussion will be restricted to evidence concerning the types of polymorphemic words playing a role in the present paper, in particular, prefixed words and nominal compounds. For reviews of the evidence concerning inflected forms, see Stemberger and MacWhinney (1986) and Levelt (1989).

Speech Errors

The evidence from speech errors concerns failures in the selection and serial ordering of morphemes in an utterance. The evidence suggests that some morphemic errors concern the lemma level, whereas others involve the lexeme level (e.g., Dell, 1986; Garrett, 1975, 1980, 1988). For example, in ‘‘how many PIEs does it take to make an APPLE?’’ (from Garrett, 1988), the interacting stems belong to the same syntactic category (i.e., noun) and come from distinct phrases. This is also characteristic of whole-word exchanges (e.g., as in ‘‘we completely forgot to add the LIST to the ROOF,’’ from Garrett, 1980), which virtually always involve items of the same syntactic category and typically ignore phrase boundaries (Garrett, 1975). This suggests that these morpheme errors and whole-word errors occur at the same level of processing. They occur when lemmas in a developing syntactic structure trade places. By contrast, the exchanging morphemes in an error such as ‘‘SLICEly THINNed’’ (from Stemberger, 1985a) belong to different syntactic categories (adjective and verb) and come from the same phrase. This is also characteristic of segment exchanges (e.g., as in ‘‘Rack Pat’’ for ‘‘pack rat,’’ from Garrett, 1988), which are typically not affected by lemma information such as syntactic class and occur on words within a single phrase. This suggests that this second type of morpheme error and segment errors occur at the same level of processing, namely the level at which lexemes are retrieved and the morphophonological form of the utterance is constructed. The errors occur when morphemes or segments in a developing morphophonological structure trade places.

In the classification of speech errors, a distinction is made between contextual and noncontextual errors. Contextual errors involve a misordering within the intended utterance, whereas for noncontextual errors there does not exist a clear source within the utterance. Morphemes of both prefixed words and compounds are involved in speech errors (all examples of errors below are from Stemberger, 1985a). Examples of contextual errors involving prefixes are the anticipation error ‘‘we have twenty-five DEdollars deductible . . .’’ for ‘‘we have twenty-five dollars deductible . . . ,’’ the perseveration error ‘‘it does not explain how an apparent case of rule EXsertion may arise’’ for ‘‘it does not explain how an apparent case of rule insertion may arise,’’ and the exchange error ‘‘a self-INstruct DE . . .’’ for ‘‘a self-destruct instruction.’’ These errors involve words of different syntactic classes, which suggests that the errors are due to encoding failures at the lexeme level. Examples of noncontextual errors involving prefixes are the substitution error ''she's so EXquisitive'' for ''she's so inquisitive,'' the addition error ''positively or negatively REmarked as . . .'' for ''positively or negatively marked as . . . ,'' and the deletion error ''they weren't _jeal_'' for ''they weren't conjealing.'' Similar errors involving prefixes have also been observed for Dutch (e.g., Poulisse, 1989). These errors are difficult to explain purely in phonological terms, because phonological errors rarely involve more than a single segment or syllable constituent (e.g., Dell, 1986; Stemberger, 1985a).

Speech error evidence also suggests that compounds have internal morphological structure in the mental lexicon. Examples of misorderings are ''oh, you were just closing the LIDBOXES'' for ''oh, you were just closing the boxlids'' and ''did we miss the TURN TRAIL-off?'' for ''did we miss the trail turn-off?'' Again, due to the large number of segments involved, these errors cannot be explained phonologically.

Although speech errors may bear on the representation of morphology in speech production, they do not reveal much about the time course of planning the production of polymorphemic words (cf. Meyer, 1992). For example, the error ''SLICEly THINNed'' does not reveal whether the base *thin* is encoded before, simultaneously with, or after the derivational affix *ly.* The question of whether morphemes are planned in serial order calls for a chronometric technique. One such technique is word pronounciation.

Word Pronounciation Latencies

In word pronounciation experiments, subjects are presented with words or pseudowords to pronounce either as they stand or in a morphologically derived form. For example, MacKay (1978) had subjects produce nominalisations from spoken verbs, such as *decision* from *decide.* Differences in pronounciation latencies have been taken as evidence for morphological derivations in producing these derived forms. However, a major problem with this task is that it forces speakers to produce a word from a perceived morphologically related word. This may evoke processes and representations that are not at play during the normal production of polymorphemic words in speech, where the production is based on semantic and syntactic features (i.e., lemma information) rather than on the perception of a base form. Moreover, by presenting a base form it is difficult to obtain an answer to the question at stake in this paper, namely whether the base is encoded before or after the derivational affix.

THE IMPLICIT PRIMING PARADIGM

To avoid some of the limitations associated with speech-error corpora and a pronounciation task, the present series of experiments employed the ''implicit priming'' paradigm developed by Meyer (1990, 1991). This paradigm involves producing words from learned paired-associates. In her experiments, subjects first learned small sets of word pairs such as *lucht–raket, berg–ravijn,* and so forth (*sky–rocket, mountain–ravine,* etc.); *lucht–raket, klerk–loket,* and so forth (*sky–rocket, clerk–ticket-window,* etc.); or *lucht–raket, rechter–bewijs,* and so forth (*sky–rocket, judge–proof,* etc.). After learning a set, they had to produce the second word of a pair (e.g., *raket*) upon the visual presentation of the first word (i.e., *lucht*). The instruction was to respond as quickly as possible without making mistakes. The production latency (i.e., the interval between prompt onset and speech onset) was the main dependent variable. An experiment comprised homogeneous and heterogeneous response sets. In a homogeneous set, the response words shared part of their form and in a heterogeneous set they did not. In the example, the responses share the first syllable (*RAket, RAvijn,* etc.) or the second syllable (*raKET, loKET,* etc.) or they are unrelated (*raket, bewijs,* etc.). Heterogeneous sets in the experiments were created by regrouping the pairs from the homogeneous sets. Therefore, each word pair was tested both under the homogeneous and the heterogeneous condition, and all uncontrolled item effects were kept constant across these conditions. Meyer found a facilitatory effect from homogeneity only when the overlap was from the beginning of the response words onward. Thus, a facilitatory effect was obtained for the set that included *RAket* and *RAvijn,* but not for the set that included *raKET* and *loKET.*

According to the WEAVER model, this seriality phenomenon reflects the suspension-resumption mechanism that underlies the incremental planning of speech. Assume the response set consists of *raket, ravijn,* and so forth (i.e., the first syllable is shared). Before the beginning of a trial, the morphological encoder can do nothing, the phonological encoder can construct the first phonological syllable (rɑ)$_\sigma$, and the phonetic encoder can recover the first phonetic syllable [rɑ]. When the prompt *lucht* is given, the morphological encoder will retrieve ⟨raket⟩. Segmental spell-out makes available the segments of this morpheme, which includes the segments of the second syllable. The phonological and phonetic encoders can start working on the second syllable. In the heterogeneous condition (*raket, bewijs,* etc.), nothing can be prepared. There will be no morphological encoding, no phonological encoding, and no phonetic encoding. In the end-homogeneous condition (*raket, loket,* etc.), nothing can be done either. Although the second syllable is known, the phonological word cannot be computed because the remaining segments are to the left of the suspension point. In the model, this means that the process has to go to the initial segments of the word, which amounts to restarting the whole process. Thus, a facilitatory effect will be obtained for the homogeneous condition relative to the heterogeneous condition for the begin condition only. Computer simulations of the experiments of Meyer (1990) can be found in Roelofs (1994, submitted-a).

The suspension-resumption mechanism can also be applied to the production of polymorphemic words. Assume the response set consists of the Dutch prefixed verbs *behalen* (*obtain*), *belopen* (*walk*), and *beschieten* (*shoot at*) sharing the prefix *be.* Before the beginning of a trial, the morphological encoder can plan the first morpheme ⟨be⟩, but not the subsequent morpheme because it is not shared. The phonological encoder can prepare the first phonological syllable (bə)$_\sigma$, and the phonetic encoder can prepare the first phonetic syllable [bə]. The remainder of the phonetic plan has to be computed during the trial itself. Thus, for polymorphemic words also initial morphemes can be prepared.

Overview of the Experiments

Experiment 1 uses the implicit priming paradigm to test the model's prediction that the constituent morphemes of compounds are planning units in speech production. If effects of morphological complexity are obtained, this means that the paradigm is sensitive to morphological structure. It would corroborate evidence from speech errors that nominal compounds are assembled out of their components during production.

The experiment tests whether the facilitatory effect from a shared segmental string that constitutes a morpheme is larger than from a segmental string that does not constitute a morpheme. For example, consider Dutch responses that share the syllable *bij.* For monomorphemic words such as *bijbel* (*bible*) consisting of the morpheme ⟨bijbel⟩, only phonological preparation is possible. In the homogeneous condition, (bɛi)$_\sigma$ and [bɛi] will have been planned for *bijbel* before the beginning of a trial, and ⟨bijbel⟩ and the second syllable will be planned during the trial itself. In the heterogeneous condition, the whole word has to be planned during the trial. By contrast, for polymorphemic words such as *bijrol* (*supporting role*) consisting of the morphemes ⟨bij⟩ and ⟨rol⟩, additional morphological preparation is possible. If ⟨bij⟩, (bɛi)$_\sigma$, and [bɛi] have been planned for *bijrol* before the beginning of a trial in the homogeneous condition, ⟨rol⟩ can be selected during the trial itself, and the second syllable can be computed. In the heterogeneous condition, however, ⟨bij⟩ has to be selected first, before ⟨rol⟩ and its segments can be selected so that the second syllable can be computed. Thus, in case of a polymorphemic word such as *bijrol*, additional morphological preparation is possible before the beginning of a trial. Consequently, extra facilitation should be obtained. Thus, the facilitatory effect for *bij* in *bijrol* (consisting of the morphemes ⟨bij⟩ and ⟨rol⟩) should be larger than the effect for *bij* in *bijbel* (⟨bijbel⟩).

In Experiment 2, the effect of sharing a noninitial constituent morpheme is assessed for nominal compounds. An end-homogeneous set in the experiment consists, for example, of *bijrol* (⟨bij⟩⟨rol⟩), *koprol* (⟨kop⟩⟨rol⟩), *deegrol* (⟨deeg⟩⟨rol⟩). Under the seriality assumption, it should not be possible to prepare a noninitial morpheme (e.g., ⟨rol⟩ in *bijrol*). Thus, whereas the model predicts a facilitatory effect from homogeneity for the initial morphemes of compounds, in this second experiment no facilitatory effect should be obtained.

In Experiments 3 and 4, prefixed verbs have to be produced. The base verbs of prefixed verbs are independent phonological words, but prefixes such as ⟨ver⟩, ⟨be⟩, and ⟨ont⟩ are not. In Experiment 3, the effect of sharing the prefix is assessed, and Experiment 4 examines the effect of sharing the base. Under the seriality assumption, it should be possible to prepare the prefix but not the base. Thus, the model predicts a facilitatory effect from homogeneity for the prefixes but not for the bases. By using trisyllabic verbs with monosyllabic prefixes and disyllabic bases, this prediction receives a strong test. Long word fragments will typically take longer to encode than short fragments (Meyer, 1990, 1991). Therefore, the advantage from preparing long fragments should be greater than from preparing short fragments. However, contrary to this, the model predicts a facilitatory effect for the short prefixes but no such effect for the long bases. Furthermore, with repeated production of the prefixed verbs, the bases still should not yield facilitation. If the absence of facilitation is due to the suspension-resumption mechanism, then the number of times the verb is produced should be irrelevant.

In Experiments 1 through 4, there is not only shared morphology but also semantic overlap. Experiment 5 addresses the influence of semantic overlap per se in the implicit priming paradigm by comparing the production of monomorphemic words in semantically homogeneous and heterogeneous sets.

Experiment 1

Method

Materials. The Dutch stimulus materials consisted of two practice sets and twelve experimental sets of three word pairs each. All response words were disyllabic. There were six different homogeneous sets and six different heterogeneous sets. Following Meyer (1990, 1991), I will refer to the homogeneity variable as Context. In the homogeneous condition, the response words shared the first syllable, whereas in the heterogeneous condition there was no such overlap. Hereafter, I will refer to the critical part of a response as the Fragment. In half of the homogeneous sets the shared syllable constituted a morpheme, whereas in the other half of the homogeneous sets it did not. Hereafter, I will refer to this morphemic variable as Status (i.e., Pseudo versus Real). The materials were obtained by an exhaustive search of the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1993). Table 1 lists the materials of the experiment.

Design. The experiment consisted of 12 experimental blocks administered consecutively. Half of the blocks included a heterogeneous set and half a homogeneous set. The first 6 blocks in the experiment were made up by three homogeneous sets followed by three heterogeneous ones (subject groups A and B) or three heterogeneous sets followed by three homogeneous ones (subject groups C and D). The first syllable of the responses constituted a morpheme (groups A and C) or it did not (groups B and D). In a block, each of the three

TABLE 1

MATERIALS OF EXPERIMENT 1: PSEUDO VERSUS REAL MORPHEMES

Pairs		
Pseudo		
religie–bijbel	graaf–hertog	teen–nagel
(religion–bible)	(count–duke)	(toe–nail)
haast–bijna	brein–hersens	volk–natie
(near–almost)	(intellect–brain)	(people–nation)
spoor–bijster	schaap–herder	dicht–nader
(trail–loss)	(sheep–sheppard)	(near–further)
Real		
studie–bijvak	boek–herdruk	mond–nasmaak
(study–subsidiary subject)	(book–reprint)	(mouth–after-taste)
toneel–bijrol	oorsprong–herkomst	echo–nagalm
(stage–supporting role)	(source–origin)	(echo–reverberation)
long–bijnier	steiger–herbouw	herfst–najaar
(lung–kidney)	(scaffolding–rebuilding)	(fall–autumn)

Homogenous			Heterogeneous		
Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Pseudo					
BIJbel	HERtog	NAgel	bijbel	bijna	bijster
BIJna	HERder	NAtie	hersens	herder	hertog
BIJster	HERsens	NAder	nader	nagel	natie
Real					
BIJvak	HERdruk	NAsmaak	bijvak	bijrol	bijnier
BIJrol	HERkomst	NAgalm	herkomst	herbouw	herdruk
BIJnier	HERbouw	NAjaar	najaar	nasmaak	nagalm

Note. An approximate English translation of the words is given in parentheses.

pairs occurred randomly eight times. Thus, there were 24 trials within a block. A pair was not repeated on adjacent trials. In the next 6 blocks, the remaining six homogeneous and heterogeneous sets were presented. Again, the first syllable of the responses constituted a morpheme (groups B and D) or it did not (groups A and C). The order of homogeneous and heterogeneous sets was counterbalanced across subjects.

Procedure and apparatus. The subjects were tested individually. They were seated in a quiet room in front of a computer screen (NEC Multisync30) and a microphone (Sennheisser ME40). After the subject had read the instructions, two practice blocks (a homogeneous and a heterogeneous one with the same structure as an experimental block, but with different items) were administered followed by the 12 experimental blocks. In the learning phase before each block, the three word pairs of a set were presented on the screen. As soon as the subject indicated having studied the pairs sufficiently, the experimenter started the test phase. The structure of a trial was as follows. First, the subject saw a warning signal (an asterisk) for 500 ms. Next, the screen was cleared for 500 ms, followed by the display of the prompt for 1500 ms. The asterisk and prompt were presented in white on a black background. Finally, before the start of the next trial there was a blank interval of 500 ms. Thus, the total duration of a trial was 3 s. The experiment was controlled by a Hermac 386 SX computer.

Analyses. After each trial, the experimenter coded the response for errors. Experimental sessions were recorded on audio tape by a Sony DTC55 DAT recorder. The recordings contained the subjects' speech and tones indicating the onset of the prompt (1 kHz) and the moment of the triggering of the voice key (2.5 kHz). These tones were also heard by the experimenter (via closed headphones) at each trial. The recordings were consulted after the experiment when the experimenter was in doubt about whether a response was fully correct. Four types of incorrect responses were distinguished. First, a subject might have produced a wrong response word. Second, the response might have exhibited a disfluency, that is, the subject stuttered, paused within the utterance, or repaired the utterance. Third, the voice key might have been triggered by a nonspeech sound (noise in the environment or a smacking sound produced by the lips or tongue). Fourth, the subject might have failed to respond within a time-out period of 1500 ms. Incorrect responses were excluded from the statistical analysis of the production latencies.

The production latencies and error rates were submitted to by-subject and by-item analyses of variance with Context, Status, and Fragment as repeated measures factors.

Subjects. The experiment was conducted with 12 paid subjects from the pool of the Max Planck Institute. All subjects were native speakers of Dutch.

Results and Discussion

Table 2 gives the mean production latencies as a function of Context and Status. The words were produced faster in the homogeneous condition than in the heterogeneous condition (the by-subject standard errors of the means were, respectively, 7.9 and 7.7 ms). Most importantly, the facilitatory effect of homogeneity was larger when the shared fragment constituted a morpheme (the Real condition) than when it did not (the Pseudo condition).

TABLE 2

MEAN PRODUCTION LATENCIES IN MILLISECONDS AND ERROR PERCENTAGES (IN PARENTHESES) FOR EXPERIMENT 1

	Context		
Status	Homogeneous	Heterogeneous	Diff
Pseudo	618 (2.7)	648 (0.4)	−30
Real	625 (3.4)	699 (2.4)	−74
Total	621 (3.0)	674 (1.4)	−53

The statistical analyses yielded a main effect of Context ($F_1(1,8) = 41.29$, $MS_e = 7154$, $p < .001$; $F_2(1,12) = 189.92$, $MS_e = 130$, $p < .001$), Status ($F_1(1,8) = 10.28$, $MS_e = 8967$, $p < .01$; $F_2(1,12) = 5.31$, $MS_e = 1446$, $p < .04$), and Fragment ($F_1(2,16) = 21.60$, $MS_e = 4588$, $p < .001$; $F_2(2,12) = 5.71$, $MS_e = 1446$, $p < .02$). Most importantly, Context interacted with Status ($F_1(1,8) = 11.06$, $MS_e = 4798$, $p < .01$; $F_2(1,12) = 34.10$, $MS_e = 130$, $p < .001$): The effect of Context was larger for the real morphemes than for the pseudo morphemes. There was no triple interaction between Context, Status, and Fragment ($F_1(2,16) < 1$, $MS_e = 4291$, $p > .80$; $F_2(2,12) < 1$, $MS_e = 130$, $p > .62$).

Table 2 also gives the overall error rate (wrong responses and disfluencies) for the homogeneous and heterogeneous conditions. The percentages for the conditions with the pseudo and real morphemes were 1.5 and 2.9. The total percentage of time-outs was 0.4 for the homogeneous condition and 0.8 for the heterogeneous condition, and the percentages of false triggering of the voice-key were, respectively, 0.8 and 0.6.

Statistical analyses of the errors yielded a main effect of Context in the by-subject analysis ($F_1(1,8) = 6.31$, $MS_e = 0.23$, $p < .04$; $F_2(1,12) = 4.64$, $MS_e = 0.12$, $p > .05$), but no effect of Status ($F_1(1,8) = 2.34$, $MS_e = 0.62$, $p > .15$; $F_2(1,12) = 1.31$, $MS_e = 0.12$, $p > .27$). Context did not interact with Status ($F_1(1,8) = 4.43$, $MS_e = 0.33$, $p > .06$; $F_2(1,12) = 4.64$, $MS_e = 0.12$, $p > .05$).

The main effect of Context for the errors might indicate that there is a speed–accuracy tradeoff in the data (e.g., Luce, 1986). On average, in the whole experiment (i.e., on the 288 trials for a subject) a single subject made four errors in the homogeneous condition and two errors in the heterogeneous condition. Thus, one might argue that subjects were faster in the homogeneous condition than in the heterogeneous condition at the cost of making more errors. Under this tradeoff hypothesis, the sizes of the Context effect for the latencies and the errors should be positively correlated. The difference in number of errors between the homogeneous and the heterogeneous condition should be larger when the difference between the corresponding latencies (i.e., the facilitatory effect) is larger. This, however, was not the case. The Pearson product–moment correlation between the error effect and the latency effect was by-subjects $r = -.02$ ($p > .94$) and by-items $r = -.46$ ($p = .05$). Thus, contrary to the tradeoff hypothesis, the correlation between the effect sizes for the latencies and errors was negative rather than positive (if anything). In short, the results of the statistical analyses of the errors do not change the interpretation of the production latencies.

The latency difference between the pseudo and real conditions emerges for the heterogeneous condition but not for the homogeneous condition. This may seem odd if the homogeneous context is supposed to produce facilitation. Direct comparisons of this sort are, however, problematic, because they involve comparisons between different words. It might simply be that the morphologically complex words have longer average latencies than do the morphologically simple words. There is little reason to expect that complexity itself would lead to such a general increase in latencies (Levelt, 1989). Word frequency is a more likely cause (cf. Jescheniak & Levelt, 1994). The simple words were of higher frequency than the morphologically complex words (means are 67 and 3 per million in the CELEX database). Given that the overlap concerned the first syllable only and given that each word occurred in both the homogeneous and heterogeneous condition, frequency cannot account for the difference in facilitatory effect between the pseudo and real conditions.

In conclusion, a facilitatory effect is obtained from homogeneity of the first syllable of disyllabic words. The effect is larger when the syllable constitutes a morpheme than when it does not: a morpheme preparation effect. The results of the experiment show that the experimental paradigm is sensitive to morphological structure. The outcome supports the idea that the component morphemes of compounds are planning units in speech production, confirming evidence from speech errors.

Speech errors suggest that compounds and prefixed words are assembled out of their morphemes in production. Furthermore, the results of Experiment 1 show that the implicit priming paradigm is sensitive to morphological structure. The next three experiments test whether successive morphemes of a compound or prefixed word have to be produced in serial order. Experiment 1 showed that the initial morpheme of compounds can be prepared. Experiment 2 looks at the effect of sharing a noninitial morpheme for these compounds. Under the seriality assumption, it should not be possible to prepare such noninitial morpheme. In the next two experiments, prefixed verbs have to be produced. In Experiment 3, the effect of sharing the prefix is assessed for these prefixed verbs, and Experiment 4 examines the effect of sharing the base. Under the seriality assumption, it should be possible to prepare the prefix but not the base. Thus, the model predicts a facilitatory effect from homogeneity for the prefixes but not for the bases. Furthermore, with repeated production of the words, sharing noninitial morphemes should still not yield a facilitatory effect.

METHOD

Materials

The Dutch materials in each experiment consisted of two practice sets and six experimental sets of three word pairs each. There were three different homogeneous and heterogeneous sets. In the homogeneous condition, the responses shared morphemes, whereas in the heterogeneous condition they did not. The materials were obtained by an exhaustive search of the CELEX lexical database (Baayen et al., 1993).

Design

Each experiment consisted of 18 experimental blocks administered consecutively. Half of the blocks included a heterogeneous set and half a homogeneous set. The first 6 blocks in the experiment (first Repetition) were made up by the three homogeneous sets followed by the three heterogeneous ones (one-half of the subjects) or the three heterogeneous sets followed by the three homogeneous ones (the other half of the subjects). Thus, after the first 3 blocks, a subject had seen all nine pairs. In a block, each of the three pairs occurred randomly six times, so there were 18 trials within a block. A pair was not repeated on adjacent trials. In the next 6 blocks, the homogeneous and heterogeneous sets were presented for the second time, but now in a different order of blocks (second Repetition). Again, three heterogeneous blocks followed the three homogeneous ones or vice versa, depending on the group of subjects. The same held for the last 6 blocks (third Repetition). The order of homogeneous and heterogeneous sets was counterbalanced across subjects.

Procedure, Apparatus, and Analyses

This was the same as in Experiment 1. The production latencies and error rates were submitted to by-subject and by-item analyses of variance with Context, Repetition, and Fragment as repeated measures factors.

Subjects

Each experiment was conducted with a different group of 12 paid subjects from the pool of the Max Planck Institute. All subjects were native speakers of Dutch.

EXPERIMENT 2

In this second experiment, subjects have to produce nominal compounds (e.g., *bijrol* ⟨bij⟩⟨rol⟩, *koprol* ⟨kop⟩⟨rol⟩, *deegrol* ⟨deeg⟩⟨rol⟩). The experiment assesses the effect of sharing a noninitial constituent morpheme (in the example, ⟨rol⟩). According to the model, it should not be possible to prepare such a noninitial morpheme of a word. Thus, in contrast to Experiment 1, the model predicts no facilitation from homogeneity of the morphemes. Table 3 lists the materials.

Results and Discussion

The compounds were produced slightly slower in the homogeneous condition than in the heterogeneous condition. The mean production latencies for the homogeneous and heterogeneous conditions were respectively 700 and 687 ms (the by-subject standard errors of these means were, respectively, 6.2 and 6.3 ms). The statistical analysis showed that there was no significant difference between these conditions ($F_1(1,10) = 1.77$, $MS_e = 14823$, $p > .21$; $F_2(1,6) = 1.34$, $MS_e = 1630$, $p > .29$). The production latencies decreased with repetition ($F_1(2,20) = 9.80$, $MS_e = 14739$, $p < .001$; $F_2(2,12) = 70.62$, $MS_e = 170$, $p < .001$). The by-subject analysis yielded a main effect of Fragment ($F_1(2,20) = 12.41$, $MS_e = 15946$, $p < .001$; $F_2(2,6) = 3.24$, $MS_e = 5091$, $p > .11$). Context did not interact with Repetition ($F_1(2,20) < 1$, $MS_e = 7677$, $p > .64$; $F_2(2,12) < 1$, $MS_e = 430$, $p > .52$) or Fragment ($F_1(2,20) = 1.12$, $MS_e = 5731$, $p > .34$; $F_2(2,6) < 1$, $MS_e = 1630$, $p > .73$). Thus, with repeated production of the compounds, still no effect of Context is obtained.

The overall error rate for the homogeneous and heterogeneous conditions was 2.5 and 1.0%, respectively. The total percentage of time-outs was 0.7 for the homogeneous condition and 0.9 for the heterogeneous condition, and the percentages of false triggering of the voice-key were, respectively, 1.4 and 1.0. The

TABLE 3

MATERIALS OF EXPERIMENT 2: NOMINAL COMPOUNDS SHARING THE SECOND CONSTITUENT MORPHEME

Pairs		
pannekoek–deegrol	gevoel–indruk	familie–stamboom
(pancake–dough roll)	(feeling–impression)	(family–pedigree)
gymnastiek–koprol	foto–afdruk	trein–spoorboom
(gymnastics–somersault)	(photo–print)	(train–barrier)
figurant–bijrol	boek–herdruk	gewicht–hefboom
(super numerary–supporting role)	(book–reprint)	(weight–power lift)

Homogeneous			Heterogeneous		
Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
deegROL	inDRUK	stamBOOM	deegrol	koprol	bijrol
kopROL	afDRUK	spoorBOOM	afdruk	herdruk	indruk
bijROL	herDRUK	hefBOOM	hefboom	stamboom	spoorboom

Note. An approximate English translation of the words is given in parentheses.

statistical analyses of the errors did not yield significant effects.

The absence of a facilitatory effect from homogeneity suggests that in producing nominal compounds, a noninitial morpheme cannot be planned in advance. Thus, the results for these polymorphemic words agree with the findings obtained by Meyer (1990) for monomorphemic words. Furthermore, with repeated production of the compounds, shared noninitial morphemes still do not yield facilitation. This suggests that preparation of noninitial morphemes cannot be learned in the course of an experiment. The results confirm the prediction of the model.

EXPERIMENTS 3 AND 4

In the next two experiments, prefixed verbs have to be produced. In Experiment 3, the effect of sharing the prefix is assessed for these prefixed verbs, and Experiment 4 examines the effect of sharing the base. In each experiment, there were three different homogeneous sets and three different heterogeneous sets. The nine experimental response words consisted of all possible combinations of three prefixes (i.e., ⟨be⟩, ⟨ont⟩, ⟨ver⟩) and three bases (i.e., ⟨halen⟩, ⟨lopen⟩, ⟨schieten⟩). The prefixes used are the most productive ones in Dutch (Lieber & Baayen, 1993). In the homogeneous condition, the response words shared the prefix or the base, whereas in the heterogeneous condition there was no such overlap. All prompts were nouns and all responses were prefixed verbs. The prompt named a typical theme/patient for the verb so that the association between prompt and response would be natural and easy to remember. Table 4 lists the materials of the experiments.

In Experiment 3, subjects have to produce prefixed verbs. The experiment assesses the effect of sharing the prefix. According to the model, it should be possible to prepare the initial morpheme of an utterance. Thus, the model predicts a facilitatory effect from homogeneity of the prefixes.

Experiment 3

Results and discussion. The prefixed words were produced faster in the homogeneous condition than in the heterogeneous condition. The mean production latencies for the homogeneous and heterogeneous conditions were respectively 657 and 684 ms (the by-subject

TABLE 4

MATERIALS OF EXPERIMENTS 3 AND 4: PREFIXED VERBS SHARING THE PREFIX (EXPERIMENT 3) OR THE BASE VERB (EXPERIMENT 4)

Pairs		
afstand–belopen	militair–beschieten	resultaat–behalen
(distance–walk)	(soldier–shoot at)	(result–obtain)
paspoort–verlopen	kleur–verschieten	gebeuren–verhalen
(passport–expire)	(color–fade)	(event–tell about)
straf–ontlopen	naam–ontschieten	vriend–onthalen
(punishment–escape)	(name–slip memory)	(friend–regal with)

Homogeneous			Heterogeneous		
Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Prefix					
ONTlopen	BElopen	VERlopen	ontlopen	ontschieten	onthalen
ONTschieten	BEschieten	VERschieten	beschieten	behalen	belopen
ONThalen	BEhalen	VERhalen	verhalen	verlopen	verschieten
Base					
beLOPEN	beSCHIETEN	beHALEN	belopen	verlopen	ontlopen
verLOPEN	verSCHIETEN	verHALEN	verschieten	ontschieten	beschieten
ontLOPEN	ontSCHIETEN	ontHALEN	onthalen	behalen	verhalen

Note. An approximate English translation of the words is given in parentheses.

standard errors of these means were 6.6 and 6.6 ms). Statistical analysis showed that the 27 ms effect of Context was significant ($F_1(1,10) = 10.36$, $MS_e = 11126$, $p < .009$; $F_2(1,6) = 20.16$, $MS_e = 477$, $p < .004$). The production latencies decreased with repetition ($F_1(2,20) = 4.76$, $MS_e = 13238$, $p < .02$; $F_2(2,12) = 13.77$, $MS_e = 381$, $p < .001$). The by-subject analysis yielded a main effect of Fragment ($F_1(2,20) = 20.08$, $MS_e = 9097$, $p < .001$; $F_2(2,6) = 3.24$, $MS_e = 4697$, $p > .11$). Context did not interact with Repetition ($F_1(2,20) < 1$, $MS_e = 6088$, $p > .47$; $F_2(2,12) = 1.69$, $MS_e = 231$, $p > .22$) but did interact with Fragment in the by-subject analysis ($F_1(2,20) = 4.21$, $MS_e = 4567$, $p < .03$; $F_2(2,6) = 3.36$, $MS_e = 477$, $p > .10$).

The overall error rate for the homogeneous and heterogeneous conditions was 3.9 and 2.3 percent, respectively. The total percentage of time-outs was 0.7 for the homogeneous condition and 1.5 for the heterogeneous condition, and the percentages of false triggering of the voice-key were, respectively, 0.4 and 0.7. The statistical analyses of the errors yielded a significant effect for Repetition only (i.e., the number of errors decreased with repetition).

The facilitation effect from Context for the prefixes is smaller than the effect for the initial compound morphemes in Experiment 1. A comparison of this sort is, however, problematic, because it involves a direct comparison between different fragments. For example, the compound morphemes are independent phonological words, but the prefixes are not. Furthermore, the segments differ.

In conclusion, the results suggest that in producing prefixed verbs, the prefix can be planned in advance. Thus, the results for these polymorphemic words agree with the findings obtained by Meyer (1990) for monomorphemic words and agree with the findings from

Experiment 1. The results confirm the prediction by the model.

In Experiment 4, subjects have to produce the same prefixed verbs as in the previous experiment. The experiment assesses the effect of sharing the base verb. According to the model, it should not be possible to prepare noninitial morphemes of an utterance. Thus, there should be no facilitatory effect from homogeneity of the bases. Furthermore, with repeated production of the prefixed verbs, the bases should still not yield facilitation.

Experiment 4

Results and discussion. The mean production latencies for the homogeneous and heterogeneous conditions were respectively 667 and 661 ms (the by-subject standard errors were 5.5 and 5.5 ms). The statistical analysis showed that there was no significant difference between these conditions ($F_1(1,10) < 1$, $MS_e = 4825$, $p > .35$; $F_2(1,6) < 1$, $MS_e = 721$, $p > .49$). The production latencies decreased with repetition ($F_1(2,20) = 30.28$, $MS_e = 7600$, $p < .001$; $F_2(2,12) = 72.94$, $MS_e = 263$, $p < .001$). There was no main effect of Fragment ($F_1(2,20) = 2.20$, $p > .13$; $F_2(2,6) < 1$, $MS_e = 6745$, $p > .76$). Context did not interact with Repetition ($F_1(2,20) < 1$, $MS_e = 11328$, $p > .80$; $F_2(2,12) = 1.10$, $MS_e = 186$, $p > .36$) or Fragment ($F_1(2,20) < 1$, $MS_e = 7277$, $p > .90$; $F_2(2,6) < 1$, $MS_e = 721$, $p > .95$). Thus, with repeated production of the prefixed words, still no effect of Context is obtained.

In the experiment, the overall error rate for the homogeneous and heterogeneous conditions was 2.0 and 1.5%, respectively. The total percentage of time-outs was 0.7 for the homogeneous condition and also 0.7 for the heterogeneous condition, and the percentages of false triggering of the voice-key were, respectively, 0.6 and 0.4. The statistical analyses of the errors did not yield significant effects.

The results of Experiment 4 suggest that in producing prefixed verbs, the base cannot be planned in advance. If phonological preparation of the base is possible, then facilitation should have been obtained. Recall that Experiment 1 provided evidence for phonological preparation of monomorphemic and polymorphemic words. If morphological preparation of the bases is possible, then a facilitatory effect should have been obtained. However, no facilitatory effect is obtained for the bases of prefixed words. This may imply that the lexical entries of prefixed words have no internal morphological structure. However, under this assumption, the evidence from speech errors for morphological structure in the form entries of prefixed words is difficult to explain (e.g., Dell, 1986; Stemberger, 1985a, 1985b). In short, the results of the experiment suggest that the noninitial bases of prefixed words cannot be planned in advance of the prefixes. Thus, the results for these polymorphemic words agree with the findings obtained by Meyer (1990) for monomorphemic words. Furthermore, with repeated production of the prefixed verbs, bases still do not yield facilitation. This suggests that preparation of noninitial morphemes cannot be learned in the course of an experiment. The results confirm the prediction by the model.

Given that there was a significant (by-subject) Context by Fragment interaction in Experiment 3, it would be worthwhile to determine whether the effect of the variable Linear order of overlapping morphemes (begin versus end) is reliable in a between-experiment statistical analysis, as is implied by the interpretation of the results. The interaction between Context and Linear order of overlapping morphemes was significant ($F_1(1,20) = 10.37$, $MS_e = 7975$, $p < .004$; $F_2(1,12) = 11.51$, $MS_e = 599$, $p < .005$). Furthermore, this interaction did not depend on Fragment ($F_1(2,40) = 1.23$, $MS_e = 5922$, $p > .30$; $F_2(1,12) = 1.02$, $MS_e = 599$, $p > .39$). So, the between-experiment analyses confirm the earlier interpretation of the results.

EXPERIMENT 5

This final experiment addresses the influence of semantic overlap in the implicit priming paradigm. The argument in Experiment 1 was that morphological overlap per se produced the extra facilitation. The difference between initial syllables constituting a morpheme (e.g., *bij* in *bijrol*) and syllables that do not (e.g., *bij* in *bijbel*) was interpreted to support the idea that morphemes are planning units in speech production. However, the semantic overlap among the response words seemed to be greater when a morpheme is shared than when it is not. Therefore, one may argue that the results reflect semantic similarity and do not mean that polymorphemic forms are morphologically analyzed in the mental lexicon. Of course, this view does not explain why the presumed facilitatory effect from semantic overlap depends on serial position. In Experiments 2 and 4, words sharing noninitial morphemes also shared part of their semantics but did not yield a facilitatory effect. The explanation of why the facilitatory effect of semantic similarity depends on linear position would require the notion of morpheme and the idea of successive encoding of morphemes. Still, it would be important to directly address the role of semantic overlap.

In the fifth experiment, subjects have to produce monomorphemic nouns. In the homogeneous sets, the nouns denote semantic category members (e.g., *dog, horse, mouse*) and in heterogeneous sets they do not. If semantic similarity is the cause of the difference between the real condition (e.g., *bijrol*) and the pseudo condition (e.g., *bijbel*) in Experiment 1, then a facilitatory effect should be obtained from semantic similarity in the current experiment.

Method

Materials. Three semantic domains were used, namely animals, clothes, and means of transportation. The homogeneous sets were *kaas–muis* (*cheese–mouse*), *mand–hond* (*basket–dog*), and *hoef–paard* (*hoof–horse*); *mouw–jas* (*sleeve–coat*), *zool–schoen* (*sole–shoe*), and *haar–pet* (*hair–cap*); *biels–trein* (*sleeper–train*), *spaak–fiets* (*spoke–bike*), and *mast–boot* (*mast–boat*). The heterogeneous sets were: *kaas–muis, zool–schoen, mast–boot; mand–hond, haar–pet, biels–trein; hoef–paard, mouw–jas, spaak–fiets.* Thus, as in the previous experiments, the prompts came from different semantic domains.

Design, procedure, apparatus, and analyses. This was the same as in Experiments 2 to 4, except that the responses in the homogeneous sets now denote semantic category members.

Subjects. The experiment was run with six new subjects from the pool of the Max Planck Institute.

Results and Discussion

The means for the semantically homogeneous and heterogeneous conditions were, respectively, 641 and 623 ms (the by-subject standard errors were 7.4 and 7.4 ms). The small inhibitory effect of 18 ms from semantic similarity was statistically significant ($F_1(1,4) = 10.48$, $MS_e = 808$, $p < .03$; $F_2(1,6) = 9.51$, $MS_e = 445$, $p < .02$). The production latencies decreased with repetition ($F_1(2,8) = 20.86$, $MS_e = 658$, $p < .001$; $F_2(2,12) = 21.68$, $MS_e = 317$, $p < .001$). The subject-analysis yielded a main effect of Semantic domain ($F_1(2,8) = 4.97$, $MS_e = 1882$, $p < .04$; $F_2(2,6) = 1.15$, $MS_e = 4065$, $p > .37$). There was no interaction between Context and Repetition ($F_1(2,8) < 1$, $MS_e = 632$, $p > .59$; $F_2(2,12) = 1.05$, $MS_e = 170$, $p > .38$) nor between Context and Semantic domain ($F_1(2,8) = 1.28$, $MS_e = 972$, $p > .33$; $F_2(2,6) = 1.40$, $MS_e = 445$, $p > .31$).

The overall error rate for the homogeneous and heterogeneous conditions was 1.0 and 0.0 percent, respectively. The total percentage of time-outs was 1.0 for the homogeneous condition and 0.0 for the heterogeneous condition, and the percentage of false triggering of the voice-key was 0.0. There were no significant effects.

In conclusion, large semantic overlap among the response words yields inhibition instead of facilitation (although for some words in Experiments 1–4 there was semantic overlap, no inhibition was obtained there presumably because the overlap was not large enough). Thus, the finding in Experiment 1 that initial syllables constituting a morpheme (e.g., *bij* in *bijrol*) produce more facilitation than syllables that do not (e.g., *bij* in *bijbel*) cannot be due to semantic similarity. The argument that morphological overlap per se is a significant cause of facilitation and that morphemes are therefore units of production planning remains supported.

Computer Simulations

The WEAVER model of form encoding in speech production (Roelofs, 1992b, 1994, submitted-a) was taken as the theoretical framework for the present paper because it is more explicit than other models about the particular issues addressed. For example, Dell (1986) adopted the hypothesis of morphological decomposition, but explored his model through computer simulation for monomorphemic words (monosyllables and disyllables) only. The revised version of this model proposed in Dell (1988) has not been explored through computer simulation, and has been applied to monomorphemic monosyllables only. The same holds for the computer implementation of Schade and Berg's (1992) version of Dell's (1988) model. Similarly, Harley (1993) implemented an interactive activation model of lexical access, but explored his model for monomorphemic monosyllables only. Finally, Stemberger (1985b) adopted the decomposition assumption in his interactive-activation model, but did not explore his model through computer simulation. Moreover, many aspects of his model relevant for the present paper are unclear. For example, although Stemberger explicitly assumed parallel activation of words in a syntactic structure ('' . . . all of the words in a clause and all the segments of a word are selected at the same time,'' Stemberger, 1985a, p. 274), it is not fully clear whether this assumption should be extended to polymorphemic words. If parallel encoding is extended to the morphological level, this would contradict the findings from the current experiments. In short, existing models of word-form encoding in speech production have ignored certain aspects of morphological complexity. One can only speculate about how these models would handle the findings from the experiments in the present paper.

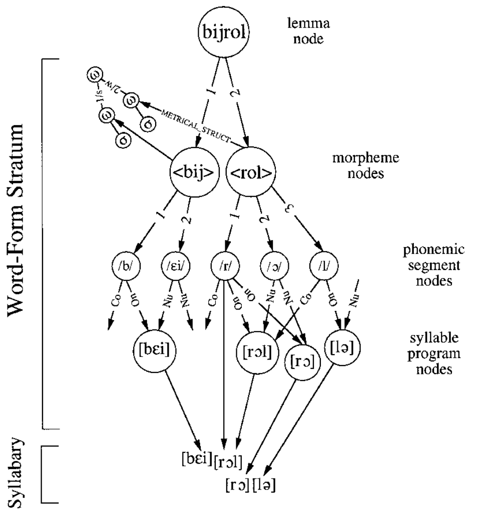


FIG. 1. Memory representation of the word form of the Dutch word *bijrol* in the model.

Overview of the WEAVER Model of Speech Production

Figure 1 illustrates the memory representation of the form of the Dutch word *bijrol* in the WEAVER model. Recall that the form lexicon is conceived of as a network. There is a metrical part and a nonmetrical part. The nonmetrical part consists of three layers of nodes: morpheme nodes, segment nodes, and syllable program nodes. Morpheme nodes stand for roots and affixes. Morpheme nodes are connected to the lemma. For example, the nodes ⟨bij⟩ and ⟨rol⟩ are connected to the lemma of *bijrol.* A morpheme node points to two major types of information, namely to its canonical metrical structure and to the segments that make up its underlying form. The metrical structure describes an abstract grouping of syllables (σ) into feet (Σ) and feet into phonological words (ω). (The foot level is ommited from the figure for reasons of simplicity.) Importantly, it is not specified which segments make up the syllables. The links between morpheme and segment nodes indicate the serial position of the segments within the morpheme. Possible syllable positions (onset, nucleus, coda) of the segments are specified by the links between segment nodes and syllable program nodes. For example, the network specifies that /l/ is the coda of [rɔl] and the onset of [lə]. These links are used in retrieving an articulatory program for a syllable after the actual syllable positions of the segments have been determined by the syllabification process.

Information is retrieved from the network through spreading of activation. Encoding starts when a morpheme node receives activation from a lemma. Activation then spreads through the network in a strictly forward fashion. Each node sends a proportion of its activation to its direct neighbors. There is also spontaneous decay of activation. Since several morphemes and their segments may be available at a particular moment in time, the encoding algorithm has to select the relevant nodes among all the activated ones in order to syllabify them. To accomplish this task, the form encoders follow simple selection rules. The rules are implemented in a parallel distributed manner. Attached to each node in the network, there is a procedure that verifies the label on the link between the node and a target node one level up. A verification procedure is triggered when the node's activation level exceeds a threshold. The procedures may run in parallel.

The morphological encoder selects the morpheme nodes that are linked to a selected lemma. Thus, ⟨bij⟩ and ⟨rol⟩ are selected for the lemma of *bijrol.* The phonological encoder selects the segments and the metrical structure that are linked to the selected morpheme nodes. The segments are associated to the syllable nodes within the metrical frame. The association proceeds from the segment whose link is labeled first to the one labeled second, and so forth. In associating the segments to the metrical frame, syllable positions (onset, nucleus, coda) are assigned to the segments following the syllabification rules of the language. Thus, in the encoding of ⟨bij⟩⟨rol⟩, the /r/ is made syllable onset, the /ɔ/ nucleus, and the /l/ coda. The phonetic encoder selects the syllable program nodes whose labeled links to the segments correspond with the syllable positions assigned to the segments. For example, [rɔl] is selected for the second phonological syllable of *bijrol,* because the link between [rɔl] and /r/ is labeled onset, between [rɔl] and /ɔ/ nucleus, and between [rɔl] and /l/ coda. In producing the plural form *bijrollen* (⟨bij⟩⟨rol⟩⟨en⟩, syllabified as $(\text{bɛi})_\sigma(\text{rɔ})_\sigma(\text{lə})_\sigma$), the /l/ will be syllabified with the plural morpheme ⟨en⟩, and the syllable program [lə] will be selected. The plural suffix in Dutch is not an independent domain of syllabification (compare the syllabification of *bijrollen* to that of *behalen,* illustrated in the introductory section of this paper). Thus, the model provides for syllabification across morpheme boundaries. If the selection conditions of a syllable program node are met, the actual selection of the node at any moment in time is a random event. The probability of selecting a node at a particular moment in time is equal to the ratio of its level of activation and the sum of the activation levels of all syllable programs nodes in the network.

The simulations involved word-form encoding up to the access of the phonetic syllabary. The mathematical equations for the spreading of activation, the selection ratio, and the expectation of the word-form encoding latency are as follows (cf. Roelofs, 1992a, 1992b, 1993, submitted-a). Activation spreads according to

$$a(k, t + \Delta t) = a(k, t)(1 - d) + \sum_n r\, a(n, t),$$

where $a(k, t)$ is the activation level of node k at point in time t, d is a decay rate ($0 < d < 1$), and Δt is the duration of a time step (in ms). The rightmost term denotes the amount of activation k receives between t and $t + \Delta t$, where $a(n, t)$ is the output of neighbor n (equal to its level of activation). The factor r indicates the spreading rate.

The probability that a target node m will be selected at $t < T \leqslant t + \Delta t$ given that it has not been selected at $T \leqslant t$, and provided that the selection conditions for a node are met, is given by the ratio

$$p(\textit{selection } m \textit{ at } t < T \leqslant t + \Delta t \mid \neg \textit{ selection } m \textit{ at } T \leqslant t) = \frac{a(m, t)}{\Sigma_i \, a(i, t)} .$$

The index i ranges over the syllable program nodes in the word-form network of a speaker. The selection ratio equals the hazard rate $h_m(s)$ of the process of the encoding of syllable m (up to the access of the syllabary) at time step s (cf. Luce, 1986, McGill, 1963; Townsend & Ashby, 1983), where $t = (s - 1)\Delta t$, and $s = 1, 2, \ldots$ The expected latency of word-form encoding up to the access of the syllabary, $E(T)$, for disyllables is

$$E_{di}(T) = \sum_{s=1}^{\infty} \{f_1(s) \sum_{j=0}^{s-1} f_2(s) + f_2(s) \sum_{j=0}^{s-1} f_1(s) + f_1(s) f_2(s)\} s\Delta t,$$

where $f_1(s)$ and $f_2(s)$ are the probability mass functions of the encoding of the first syllable and second syllable, respectively.

The parameter values were kept the same as in the simulations reported in Roelofs (1994, submitted-a). The spreading rate r within the word-form stratum was 0.0120 [ms^{-1}], the decay rate d was 0.0240 [ms^{-1}], and the size of the external input to the network *extin* was 0.1965 [ms^{-1}]. The activation threshold for the triggering of a selection test was 1.5. The duration of basic events such as the time for the activation to cross a link, the latency of a selection test, and the syllabification time per syllable equalled $\Delta t = 25$ ms. The completion time of a morphemic procedure was twice as long.

In the simulations of the experiments, the begin-homogeneous response sets consisted of *bijrol* (⟨bij⟩⟨rol⟩), *bijnier* (⟨bij⟩⟨nier⟩), and so forth (Status: Real), versus *bijbel* (⟨bijbel⟩), *bijster* (⟨bijster⟩), and so forth (Status: Pseudo). An end-homogeneous set consisted of *bijrol* (⟨bij⟩⟨rol⟩), *koprol* (⟨kop⟩⟨rol⟩), and so forth. The heterogeneous sets were created by recombining the responses of different homogeneous sets. The critical items were embedded in a network which coded the forms of 50 other words randomly selected from the CELEX lexical database (no embedding produced the same simulation outcomes). Advance knowledge about the form of the response words was simulated by completing the morphological, phonological, and phonetic encoding of the word form as far as possible before the beginning of a trial.

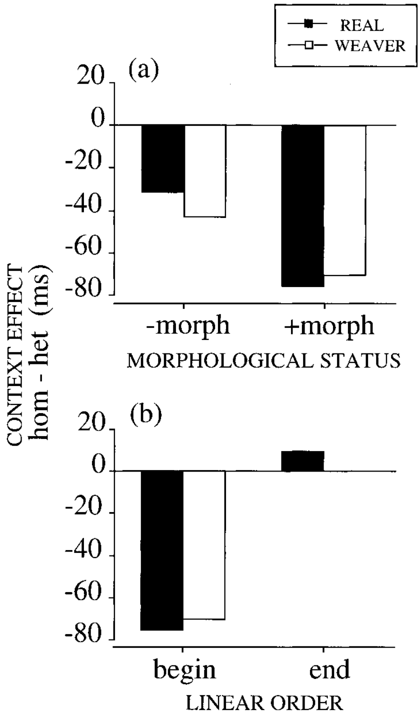


FIG. 2. Results of the computer simulations.

Figure 2 shows the results of the simulations. Panel (a) shows the results of the simulation of Experiment 1. Sharing *bij* in *bijrol* and *bijbel* yields a facilitatory effect. The facilitatory effect for *bij* in *bijrol* (consisting of the morphemes ⟨bij⟩ and ⟨rol⟩, the +MORPH condition) is larger than the facilitatory effect for *bij* in *bijbel* (⟨bijbel⟩, the −MORPH condition). This corresponds to the experimental findings. Panel (b) shows the results of the simulation of Experiments 1 and 2 (similar to those of Experiments 3 and 4). A facilitatory effect is obtained when the responses share the first morpheme (*bijrol, bijnier,* etc., the BEGIN condition), but not when they share the second morpheme (*bijrol, koprol,* etc., the END condition). This corresponds to the experimental findings. To conclude, the simulations demonstrate that the WEAVER model accounts for the empirical phenomena.

General Discussion

The present work deals with the largely neglected issue of the role of morphology in lexical access in speech production. The aim of the current research was to examine whether the successive morphemes of a word are planned in serial order. In particular, I investigated whether the speech production system can plan noninitial morphemes of a word before initial ones. Five experiments were reported that tested predictions of the WEAVER model of form encoding that assumes seriality in planning the production of polymorphemic words. The results of the experiments supported the assumption of serial planning of morphemes. It was shown by computer simulation that the model accounts for the findings. In this final section, I will discuss a number of empirical and theoretical issues that are raised by the research.

Advance Planning and the Initiation of Articulation

The issue of advance planning pertains to the relationship between the generation of the speech plan and articulation (e.g., Gordon & Meyer, 1987; Sternberg, Knoll, Monsell, & Wright, 1988). How much of the speech plan for a word has to be completed before articulation is initiated? The critical fragment would be minimal if articulation is initiated when the speech plan for the word onset is completed, and it would be maximal if articulation is initiated upon completion of the plan for the whole word. Various intermediate positions are possible.

The absence of a facilitatory effect for the noninitial morphemes in Experiment 2 and 4 may have a rather trivial explanation, namely, that the experimental paradigm is not able to pick up an effect of their preparation. If articulation begins upon completion of the first compound syllable or the prefix syllable, an effect of preparation of the second compound syllable or the base syllables of the prefixed words will not be picked up.[2] There exist at least two empirical arguments against the view that the second syllable is not involved in the initiation of articulation.

First, Meyer (1990, 1991) observed that longer fragments yield larger facilitatory effects than shorter fragments. In particular, the facilitatory effect was larger when the responses shared both the first and (part of) the second syllable than when only the first syllable was shared. This suggests that the second syllable is involved in the initiation of articulation of a word.

Second, I had subjects produce simple phrasal forms, in particular, Dutch verb-particle combinations, which consist of two embedded phonological words corresponding to the particle and the base verb (Roelofs, submitted-b). In producing particle verbs in a particle-first infinitival form, the facilitatory effect was larger when the responses shared both the particle syllable and the first base syllable than when only the particle syllable was shared. For example, the effect was larger for *uitleven, uitlezen, uitlenen* (*uit* is the particle syllable and *le* is the first base syllable) than

[2] Alternatively, one may argue that onset latencies are simply insensitive to the encoding of elements that are discontinuous with initial segments. Meyer and Schriefers (1991), however, obtained facilitatory effects from spoken second-syllable primes (presented via headphones) in picture naming. These results have been replicated with spoken primes in the implicit-priming paradigm (Roelofs, submitted-a).

for *uitzoeken, uitdraaien, uitgeven* (sharing the particle *uit* only). This suggests that planning the second phonological word of these verbs determines the initiation of articulation rather than planning the first phonological word only.

In sum, if articulation is initiated upon completion of (part of) the first syllable, overlap that crosses the first syllable boundary should not increase the facilitatory effect. The empirical evidence shows, however, that the facilitatory effect becomes larger when overlap crosses the first syllable boundary or the first phonological word boundary. If (part of) the first syllable would suffice, then the increase of the facilitatory effect due to homogeneity of the second syllable remains unexplained. To conclude, a facilitatory effect from preparing the second compound morpheme and the bases of prefixed verbs could have been picked up in Experiments 2 and 4.

Decomposition versus Full Listing

Under the full listing assumption, whole-word forms rather than their constituent morphemes are represented in the mental lexicon (e.g., ⟨bijrol⟩ and ⟨bijbel⟩); under the decomposition assumption, the constituent morphemes are stored (e.g., ⟨bij⟩, ⟨rol⟩, and ⟨bijbel⟩). If constituent morphemes are not represented, they cannot be planning units in speech production.

The WEAVER model assumes that syllabifications of words are computed rather than stored. Other models such as Dell's (Dell, 1986, 1988) assume that syllabifications are stored with words in memory. According to models with an active syllabification process, the syllabification process in word-form encoding has to know the morphemic source of the segments that are input to the process. The process cannot blindly accept a string of segments and syllabify the segments without taking morpheme boundaries into account. This implies that the lexical entries have to indicate morpheme boundaries.

The outcomes of Experiment 1 suggest that component morphemes of compounds are planning units in speech production, and therefore support the decomposition view rather than the full listing view for these words. The effect of morphological structure is difficult to explain under the full listing hypothesis. According to this hypothesis, words such as *bijrol* and *bijbel* would have the same structure at the morphemic level, namely ⟨bijrol⟩ and ⟨bijbel⟩ instead of ⟨bij⟩⟨rol⟩ and ⟨bijbel⟩. In conclusion, the experiment provides evidence for a morphologically decomposed representation of compounds, corroborating existing evidence from speech errors.

What Is Serial in the Planning Process?

The outcomes of Experiment 1 support the decomposition hypothesis. In a decomposition view, the morphemes of a word may be planned in parallel or in a serial fashion. The outcomes of Experiments 2, 3, and 4 suggested that the successive morphemes of a polymorphemic word are planned in serial order.

What exactly is serial in the planning process? As the computer simulations demonstrated, the current findings do not imply that every aspect of planning the production of polymorphemic words is serial. For example, seriality may hold for the application of production rules but not for the activation of memory elements. The production rules in the WEAVER model give rise to rightward incrementality, but the morphemes and the phonemic segments of a word in memory are activated in parallel. For example, the representations /b/, /ɛi/, /r/, /ɔ/, and /l/ for *bijrol* are simultaneously activated. According to the model, seriality reflects the fact that ⟨bij⟩ is selected before ⟨rol⟩ and that the /b/ is selected and syllabified before the /r/ (i.e., the working of production rules) rather than the activation of these elements in memory.

CONCLUSION

The research reported in this paper provides evidence that the speech production system has to plan the forms of the successive morphemes of a polymorphemic word in serial order. The results suggest that the system cannot plan noninitial morphemes of a word before initial ones, even when these noninitial morphemes constitute fully fledged phonological words of their own. Thereby, the experiments confirm predictions of the WEAVER model of word-form encoding in speech production (Roelofs, 1992b, 1994, submitted-a).

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