Morpheme frequency in speech production: Testing WEAVER

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1. INTRODUCTION

This paper addresses the issue of whether the form lexicon underlying speech production contains morphologically decomposed entries. Two major psycholinguistic views on morphological complexity are the full listing hypothesis and the decomposition hypothesis (Butterworth 1983). Under the full listing hypothesis the lexical representations of polymorphemic forms are morphologically unanalysed, whereas under the decomposition hypothesis they are analysed in their constituent morphemes. If constituent morphemes are not stored with words in memory, they cannot be used in assembling word forms during production. Thus, only decomposed form entries allow morphemes to be planning units in speech production. The aim of this paper is to provide (new) evidence for the idea that the active form lexicon of languages such as Dutch contains morphologically decomposed entries. This is done by showing the influence of morpheme frequency on lexical access in planning the production of speech.

The theoretical background of this study is the spreading-activation theory and computer model of lexical access in speaking developed in Roelofs (1992a, 1992b, 1993, 1994, 1996, submitted-a) and the theoretical framework for the access process proposed by Levelt (1989, 1992; Levelt & Wheeldon 1994). Lexical access is conceived of as a process comprising two major stages, called lemma retrieval and word-form encoding. In conceptually driven lemma retrieval, a lexical concept is mapped onto the lemma of a corresponding word. A lemma is a memory representation of a word's syntactic properties such as syntactic class, grammatical gender, and subcategorization features. In word-form encoding, the lemma is mapped onto stored syllable-based motor programs (i.e., word-form encoding creates the phonetic plan). This is accomplished by temporarily grouping the segments of the word's morphemes into phonological syllables (this process is referred to by Levelt as "syllabification on the fly"). The form representation in memory of a word's morphemes and segments is sometimes called its "lexeme" (Kempen & Huijbers 1983). Finally, the phonological syllables are used to address the motor programs in a syllabary. A syllabary is a repository of articulatory-phonetic programs for syllables. The component of the computer model of lexical access that concerns the encoding of word forms is called WEAVER (Word-form Encoding by Activation and VERification).

The argument for morphologically decomposed entries is laid out in this paper as follows. First, I review a number of recently discovered frequency effects in lexical access in speech production and I briefly indicate how the WEAVER model accounts

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for them. Second, I explain why the word-form encoding algorithm in the model requires that the lexical entries of certain classes of polymorphemic words are morphologically decomposed. I also review the existing evidence for morphological decomposition in production. Next, I indicate why morpheme frequency effects are to be expected in WEAVER. Third, a new experiment testing this prediction is described. The results show the influence of morpheme frequency on lexical access in planning the production of spoken words.

2. FREQUENCY EFFECTS IN SPEECH PRODUCTION

Recent studies suggest that in the process of lexical access in speech production, three loci of frequency effects should be distinguished. These effects of frequency of usage have been obtained with production tasks that did not include reading words aloud ("word pronunciation"), so the effects should be attributed to lexical access in speech production rather than to accessing the comprehension lexicon. First, there is a frequency effect in accessing lemma information such as a word's grammatical gender. Second, there is an effect in accessing a word's lexeme. Third, there is an effect in accessing the syllabary. Relevant for the current paper is the finding that the frequency effect in lemma retrieval disappears with repeated production of a word, whereas the effect in lexeme access is robust over repetitions.

Lemma-level frequency effects. Experiments by Jescheniak and Levelt (1994; Jescheniak 1994) show that when lemma information such as grammatical gender is accessed, a frequency effect is obtained. For example, Dutch participants had to decide on the gender of a picture's name (e.g., they had to decide that the grammatical gender of the Dutch word *hamer* is nonneuter), which was done faster for high-frequency words than for low-frequency ones. The effect disappeared over repetitions, contrary to a "robust" frequency effect obtained in naming the pictures (cf. Wingfield 1968).

Lexeme-level frequency effects. Jescheniak and Levelt (1994) provided evidence that the locus of the robust frequency effect is the lexeme level. When participants had to respond to an English probe word by producing its Dutch translation equivalent, the production latency of a low-frequency homophone was determined by the sum frequency of that word and its high-frequency counterpart. For example, participants had to produce the Dutch word *bos* in response to *bunch* (low-frequency reading). The production latencies for these homophones were compared to the latencies for two types of other words. First, there were low-frequency control words whose frequency was matched to that of the low-frequency reading of the homophone. The low-frequency control for *bos* was *hok* (*kennel*). Second, there were high-frequency control words whose frequency was matched to the sum frequency of the low-frequency reading (i.e., *bunch*) and high-frequency reading (i.e., *forest*) of *bos*. The high-frequency control for *bos* was *hoek* (*corner*). Producing the homophones (*bos*) in their low-frequency reading went as fast as producing the high-frequency controls (*hoek*), and it went faster than producing the low-frequency

controls (*hok*). A low-frequency homophone inherits the frequency of its high-frequency counterpart. Homophones share the lexeme in common but not the lemma (Jescheniak & Levelt 1994, and Dell 1990, also takes this point of view). By sharing the lexeme, a low-frequency homophone inherits the frequency of its high-frequency counterpart. This explains the homophone effect observed by Jescheniak and Levelt.

A related homophone effect has been obtained with speech errors. Studies of sound-error corpora suggest that slips of the tongue occur more often on low-frequency words than on high-frequency ones (e.g., Stemberger & MacWhinney 1986). That is, segments of frequent words tend not to be misordered. Research of Dell (1990) has shown that low-frequency homophones adopt the relative invulnerability to errors of their high-frequency counterparts. Homophones share the lexeme in common, which would explain why low-frequency homophones inherit the error properties of their high-frequency counterparts. Also in line with the results of Jescheniak and Levelt (1994) are Nickels' (1994) findings from aphasic speakers. She observed an effect of frequency on phonological errors (i.e., errors in word-form encoding) but no effect of frequency on semantic errors (i.e., errors in conceptually driven lemma retrieval). These findings suggest that the locus of the effect of frequency on speech errors is the lexeme level (cf. Harley 1994; but see Dell 1990).

Syllabary-level frequency effects. Research by Levelt and Wheeldon (1994) suggests that in accessing the syllabary, a frequency effect is obtained that is independent of the lexeme-level frequency effect. Relevant for the current study is that the effect observed by Levelt and Wheeldon did not occur on the first syllable of a word. That is, in producing disyllables, an effect of frequency was obtained for the second syllable of the word but not for the first syllable.

Elsewhere (in Roelofs, submitted-a), I have shown by computer simulation that the WEAVER model accounts for the word-level frequency effects obtained by Jescheniak and Levelt, the sublexical effects obtained by Levelt and Wheeldon, and the independence of these types of frequency effect. WEAVER conceives of the word-form lexicon as a network of morphophonological procedures and nodes and labeled links. The network is accessed by spreading of activation. Activation of nodes triggers procedures that build incrementally a phonetic plan. Upon activation of a node, a procedure verifies the link between the node and the selected nodes one level up in the network. Three form-encoding stages are involved: morphological, phonological, and phonetic encoding. Morphological procedures select the morpheme nodes that appropriately encode a selected lemma and its tense, agreement, and mood parameters. This stage thus concerns what is traditionally called the "syntax-morphology interface" (e.g., Spencer 1991). Phonological procedures select the segments of the morphemes and syllabify the segments in order to construct so-called phonological syllables as constituents of phonological word representations. This stage thus comprises what is traditionally called the "morphology-phonology interface" (e.g., Goldsmith 1990). Finally, phonetic procedures select the syllable-based motor programs that appropriately encode these phonological syllables. This final encoding stage thus concerns what is sometimes called the "postlexical phonology"

(e.g., Goldsmith 1990). Frequency effects in the model originate from differences in the speed of running procedures. Speed depends on frequency of usage.

3. A CASE FOR MORPHOLOGICALLY DECOMPOSED LEXEMES

3.1. *Computational argument*

The encoding algorithm of WEAVER requires that certain classes of polymorphemic words have morphologically decomposed entries in the output word-form lexicon (see Roelofs 1996, submitted-a). The computational argument for making explicit morpheme boundaries is a rather old one (e.g., Chomsky & Halle 1968). In languages such as Dutch, morphemes such as prefixes, particles, the base verbs of particle verbs and prefixed verbs, and some suffixes constitute independent domains of syllabification (Booij 1983, 1995). In Dutch, this holds for prefixes such as *ver-*, *ont-*, and *be-*, particles such as *op*, *af*, *aan*, *uit*, and so forth, and suffixes such as *-baar*, *-zaam*, *-achtig*, and *-heid*, but not for suffixes such as *-in*, *-er*, and *-ing*. For example, the segment /r/ of the prefix *ver-* of the Dutch verb *vereren* (*honour*) is not syllabified with the base verb *eren*, as the maximal onset principle in syllabification would predict, but is syllabified as the coda of *ver-*. This does not hold for a pseudo-prefixed verb such as *verifiëren* (*verify*), where the /r/ is the onset of the second syllable *ri* instead of the coda of *ver*. Similar to the prefixed verb *vereren*, the /t/ of the particle verb *uitademen* (*breathe out*) is syllabified with the particle *uit* (*out*) and not with the base verb *ademen* (*breathe*). Also, the final segment /r/ of the base *kinder* (*child*) in *kinderachtig* (*childish*) is syllabified with the base and not with the suffix *-achtig* (contrary to the English translation equivalent). By contrast, the final segment /w/ of *leeuw* (*lion*) in *leeuwin* (*lioness*) is syllabified with the suffix *-in* (*-ess*).

The component morphemes of Dutch compounds also constitute independent domains of syllabification. For example, the Dutch nominal compound *handappel* (*eating-apple*) consists of the morphemes <hand> and <appel>. The segment /d/ of *hand* in *handappel* is not syllabified with *appel* as the principle of maximization of onset would predict, but is syllabified as the coda of *hand*. Thus, *handappel* is syllabified as (hɑnd)$_\sigma$ (ɑp)$_\sigma$ (pəl)$_\sigma$. This does not hold for synchronically pseudo-complex words such as *aardappel* ("*earth apple*", *potato*), which is syllabified as (ar)$_\sigma$ (dɑp)$_\sigma$ (pəl)$_\sigma$. In WEAVER, *aardappel* is represented by one node <aardappel> at the morphological level, whereas *handappel* is represented by two nodes, one for <hand> and one for <appel>. Thus, in morphological encoding, the lemma node of the word *aardappel* is mapped onto one morpheme node, just like the lemma node of a simple word like *hamer* (*hammer*) is, whereas the lemma node of the compound *handappel* is mapped onto two morpheme nodes. In the next processing step, phonological procedures select the segments linked to these morpheme nodes and syllabify the segments taking each morpheme as a domain of syllabification.

The examples given above illustrate that the syllabification process in word-form encoding has to know the morphemic source of the segments that are input to

the process. The syllabification algorithm cannot blindly accept a string of segments and syllabify the segments without taking morpheme boundaries into account. This implies that the lexical entries of certain words have to indicate morpheme boundaries. That is, the lexicon of a Dutch speaker has to contain morphologically decomposed entries. Note that morpheme boundaries have to be made explicit in lexical entries in case of an active syllabification process, not when syllable structure is stored with words in memory (e.g., as in the model of Dell 1988).

3.2. *Empirical evidence: speech errors and pronunciation latencies*

The literature on the morphological processes and structures underlying speech production provides some support for the assumption of a morphologically decomposed lexicon. But, as I argue below, some of the findings should be interpreted with caution. Until recently, the empirical evidence has mainly come from two sources: speech errors in normal and aphasic speakers, and production latencies obtained with a word pronunciation task. In general, whereas morphological complexity has received much attention in the study of language comprehension (for overviews and references, e.g., Henderson 1985, for the visual domain, and e.g., (for Dutch) Schriefers, Zwitserlood, & Roelofs 1991, and Marslen-Wilson, Tyler, Waksler, & Older 1994 for the auditory domain) as well as in the study of language acquisition (especially inflectional morphology; for an overview and references, e.g., Pinker & Prince 1988), it has largely been ignored in the study of real-time language production. For a recent collection of papers on morphological complexity, I refer to Sandra and Taft (1994).

The evidence from speech errors concerns failures in the selection and serial ordering of morphemes in an utterance. The available 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 sound 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 sound errors occur at the same level of processing, namely the level at which lexemes are retrieved and the morphophonological form of the utterance is con-

structed. The errors occur when morphemes or sounds in a developing morpho-phonological 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 affixed 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". Note that the errors concern 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". 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). Thus, if the form entries of prefixed words had no internal morphological structure, these errors concerning prefixes would be difficult to account for. 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 purely in phonological terms.

In summary, the distributional characteristics of some morpheme errors are similar to those of sound errors and differ from those of whole-word errors. This supports the idea that the lexicon involved contains morphologically decomposed lexemes. Speech errors are rare events. By definition, speech errors reflect unusual circumstances that cannot be straightforwardly be taken to represent the norm. It may be possible that speakers normally do not assemble a word's form out of its constituent morphemes, but start to make errors when they occasionally try to do so. In short, converging evidence from other sources for morphemic structure in production would be most welcome.

In word pronunciation experiments, participants are presented with words or pseudowords which have to be pronounced either as they stand or in a morphologically derived form. For example, MacKay (1978) had participants produce nominalisations from spoken verbs, such as *decision* from *decide*. Differences in pronunciation latencies have been taken as evidence for the occurrence of morphological derivations in producing these derived forms. A major problem with word pronunciation is that the task 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.

4. THE IMPLICIT PRIMING PARADIGM

In this paper, the case for morphological decomposed lexemes in production is made by, first, showing that effects of morpheme frequency can be obtained in a chronometrical paradigm (thereby cross-validating evidence for morphological structure from speech errors) and, second, by showing that the effect of morpheme frequency does not disappear with repeated production of the words, which suggests that the locus is the lexeme level. Recall that the lemma-level effect of Jescheniak and Levelt disappeared over repetitions, whereas their lexeme-level effect did not. In investigating morpheme frequency effects and their (in)dependence of repetition, I make use of the speech-preparation paradigm developed by Meyer (1990, 1991). Meyer coined it the "implicit priming" paradigm. This paradigm avoids some of the limitations associated with a word pronunciation task. The paradigm involves producing words from learned paired-associates. In the experiments of Meyer, Dutch participants first learned small sets of word pairs such as *lucht* - *raket*, *berg* - *ravijn*, and so forth (*sky* - *rocket*, *mountain* - *ravine*, etc.); or *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.). Next, 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 or prompt (i.e., *lucht*). On each trial, randomly one of the prompts was presented. The response words were all monomorphemic and were not morphophonologically related to the prompt. The participants were instructed 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 in common 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 different 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.

A main finding from these experiments was that a facilitory effect from homogeneity was obtained only when the overlap was from the beginning of the response words onward. Thus, a facilitory effect was obtained for the set that included *RAket*, *RAvijn*, etc., but not for the set that included *raKET*, *loKET*, etc.

According to WEAVER, the seriality phenomenon observed by Meyer should be attributed to the suspension-resumption mechanism that underlies the incremental

planning of speech. The three processing stages in WEAVER (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 till it gets new input. When further information is provided, the encoding stage is resumed.

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 $(\text{ra})_\sigma$, and the phonetic encoder can recover the first motor program [ra] from the syllabary. When the prompt *lucht* is given, the morphological encoder will retrieve the node <raket>. Segmental spellout makes available the segments of this morpheme, which includes the segments of the second syllable. So, the phonological encoder and the phonetic encoder can start working on the second syllable.

This suspension-resumption mechanism explains the findings of Meyer as follows. Before the beginning of a trial in the begin-homogeneous condition, the morphological encoder can do nothing, but the phonological and phonetic encoders encode the first syllable. After having encoded the first syllable, the encoders wait till they receive further input information. In the heterogeneous condition, nothing can be prepared. There will be no morphological encoding, no phonological encoding, and no phonetic encoding. In the end-homogeneous condition, 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 facilitory 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).

5. SERIAL ORDER IN PLANNING MORPHEMES

Recently, the implicit priming paradigm has been applied to the production of polymorphemic forms (Roelofs 1996). WEAVER predicts that a larger facilitory effect should be obtained when shared initial segments constitute a morpheme than when they do not. For example, the effect should be larger for sharing the syllable *bij* in response sets including Dutch compounds such as *bijrol* (morphemes <bij> and <rol>, *supporting role*) than for sharing the syllable *bij* in sets including simple words such as *bijbel* (morpheme <bijbel>, *bible*). For monomorphemic words like *bijbel* consisting of the morpheme <bijbel>, sharing the first syllable *bij* allows phonological preparation only. In contrast, for polymorphemic words like *bijrol* consisting of the morphemes <bij> and <rol>, additional morphological preparation is possible.

When the monomorphemic word *bijbel* is in a homogeneous condition where the

responses share the syllable *bij*, the phonological syllable (bεi)$_{\sigma}$ and the motor program [bεi] can be planned before the beginning of a trial. The morpheme <bijbel> and the second syllable *bel* will be planned during the trial itself. In a heterogeneous condition where the responses do not share part of their form, the whole monomorphemic word *bijbel* has to be planned during the trial. When the polymorphemic word *bijrol* is in a homogeneous condition where the responses share the syllable *bij*, the first morpheme <bij>, and the phonological syllable (bεi)$_{\sigma}$ and the motor program [bεi] may be planned before the beginning of a trial. Thus, the second morpheme node <rol> can be selected during the trial itself, and the second syllable *rol* can be encoded at the phonological and the phonetic level. In the heterogeneous condition, however, the initial morpheme node <bij> has to be selected first, before the second morpheme node <rol> and its segments can be selected so that the second syllable *rol* can be encoded. 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 facilitory effect for *bij* in *bijrol* (consisting of the morphemes <bij> and <rol>) should be larger than the effect for *bij* in *bijbel* (<bijbel>).

The outcomes confirmed the predictions by WEAVER. In producing disyllabic simple and compound nouns, a larger facilitory effect was obtained when a shared initial syllable constituted a morpheme than when it did not. For example, the effect was larger for *bij* in *bijrol* (<bij> and <rol>) than for *bij* in *bijbel* (<bijbel>).

The outcomes of further experiments supported WEAVER's claim that successive morphemes are planned in a rightward fashion. In producing nominal compounds, no facilitation was obtained for noninitial morphemes. For example, no effect was obtained for <rol> in *bijrol*. In producing prefixed verbs, a facilitory effect was obtained for the prefix but not for the noninitial base. For example, a facilitory effect was obtained for the prefix <be> of *behalen* (*to obtain*), but not for the base <halen>.

Another series of experiments tested predictions of WEAVER about the generation of polymorphemic forms in simple phrasal constructions, namely Dutch verb-particle combinations (Roelofs, submitted-b). Particle verbs are not words but minimal verb projections (Booij 1995). Given that the semantic interpretation of particle verbs is often not simply a combination of the meanings of the particle and the base, the verb-particle combinations have to be listed in the mental lexicon. WEAVER employs morphologically decomposed lexemes in storing particle verbs, prefixed verbs, and compounds. However, while prefixed words and compounds are represented by a single lemma node at the syntactic level, particle verbs comprise two lemma nodes. In producing a verb-particle construction, the lemma retriever recovers these two lemma nodes from memory and makes them available for syntactic encoding processes, whereas in producing a prefixed verb or a compound, only a single lemma node is retrieved. In examining the production of particle verbs, again the implicit priming paradigm was used.

For particle-first infinitive forms, a facilitory effect was obtained when the responses shared the particle but not when they shared the base. For example, in

producing *opzoeken* (*look up*), a facilitory effect was obtained for the particle *op* (*up*) but not for the base *zoeken* (*look*). In particle verbs, the linear order of the major constituents can be reversed without creating another lexical item. For base-first imperative forms, a facilitory effect was obtained for the bases but not for the particles. For example, in producing "zoek op!", a facilitory effect was obtained for *zoek* but not for *op*. As predicted by WEAVER, the facilitory effect was larger for the bases than for the particles (i.e., larger for *zoek* in "zoek op!" than for *op* in *opzoeken*). Bases like *zoek* are longer and of lower frequency than particles like *op*. Long fragments of low frequency take longer to encode than short fragments of high frequency, so the facilitory effect from preparation will be higher. Subsequent experiments excluded that this difference in effect was due to the verb's mood or to the length of the nonoverlapping part, and provided evidence for an independent contribution of length and frequency. First, the facilitory effect increased when the overlap became larger with frequency constant. The facilitory effect increased when the number of segments in the particle increases. For example, the effect was larger for *door* (CVVC) in *doorschieten* (*overshoot*) than for *aan* (VVC) in *aanschieten* (*dart forward*). Also, the effect was larger when the responses shared the particle and the first base syllable such as *ople* in *opleven* (*revive*) than when they shared the particle only such as *op* in *opzoeken* (*look up*). Second, bases of low frequency yielded larger facilitory effects than bases of high frequency with length constant. For example, the effect was larger for *veeg* (low frequency) in "veeg op!" ("clean up!") than for *geef* (high frequency) in "geef op!" ("give up!").

The results obtained with the items sharing the particle and the first base syllable (e.g., *ople* in *opleven*) are of special interest. The absence of a facilitory effect for the bases and particles in second position (i.e., *zoeken* in *opzoeken* and *op* in "zoek op!") in the earlier experiments does not necessarily imply that there was no preparation of these items. The particles and the bases in the first position of the utterances are independent phonological words. Articulation may have been initiated upon completion of (part of) this first phonological word in the utterance (i.e., *op* in *opzoeken* and *zoek* in "zoek op!"). If this was the case, then the speech onset latencies simply did not reflect the preparation of the second phonological word, even when such preparation would actually have occurred. The results for sharing *ople* in *opleven* show, however, that the facilitory effect increases when the overlap crosses the first phonological word boundary. In producing particle verbs in a particle-first infinitive form, the facilitory effect is larger when the responses share both the particle syllable and first base syllable than when only the particle syllable is shared. This suggests that planning (a critical part of) the second phonological word (the base verb) determines the initiation of articulation rather than planning the first phonological word (the particle) only.

6. SEMANTIC TRANSPARENCY

Roelofs and Baayen (in preparation) examined the role of semantic transparency in planning the forms of polymorphemic words. According to WEAVER, morphological complexity can play a role in form planning without having a synchronic semantic motivation.

First, the syllabification of some words requires that morphemes are present in words that are semantically opaque. Diachronically, compounds like *aardappel* (*patato*) and *oogappel* (*apple of my eye*) may perhaps be semantically transparent (e.g., *aardappel* means literally "earth apple") but synchronically they are not. The word *oogappel* is syllabified in the same way as the semantically transparent word *handappel* (*eating apple*), whereas *aardappel* is syllabified as a morphologically simple word. The /x/ is the coda of *oog* and not the onset of *appel*. In contrast, the /d/ of *aardappel* is syllabified with *appel* (following the maximal onset principle in syllabification), which suggests that there is no morpheme boundary between *aard* and *appel*. Thus, the syllabification of *aardappel* and *oogappel* requires that the semantically opaque word *oogappel* is stored in a morphologically decomposed fashion whereas the semantically opaque word *aardappel* is not. In WEAVER, *oogappel* is represented by two morpheme nodes <oog> and <appel>, whereas *aardappel* is represented by one node <aardappel>.

Second, in contrast to simple verbs and particle verbs, Dutch prefixed verbs do not take <ge> in forming the past participle and the refusal to take <ge> is independent of transparency. For example, although *ontkorsten* (*remove crust*) is fully transparent and *ontbijten* (*have breakfast*) is opaque, neither of them takes the past particle <ge>. This may be explained by assuming that opaque prefixed verbs such as *ontbijten* are stored as simple forms together with a diacritic that says that they do not take <ge>. However, the class of verbs that does not take <ge> is not arbitrary but well-defined, namely it is the class of verbs that are prefixed. If semantically opaque prefixed verbs are stored as complex verbs, the presence of a prefix in memory (e.g., the node <ont>) might block prefixation with <ge>.

Third, the past tense form of prefixed verbs typically corresponds to the past tense form of the base and this is independent of transparency. For example, *bijten* (*to bite*) is a strong verb (i.e., has an irregular past tense). The past tense of *bijten* is irregular *beet* rather than regular *bijtte*. Similarly, the past tense of the prefixed verb *ontbijten* is *ontbeet* rather than *ontbijtte*. The inheritance of the irregular past tense would readily be explained if opaque prefixed verbs are stored as complex forms.

Two implicit priming experiments examined the role of semantic transparency in planning the forms of prefixed verbs. Earlier, we saw that implicit priming is sensitive to morphological planning. In producing simple and compound nouns, a larger facilitory effect is obtained when a shared initial syllable constitutes a morpheme than when it does not. So, there is an interaction between homogeneity and type of noun. On each trial in the experiments examining the role of semantic transparency, participants had to produce one prefixed word out of a set of three as quickly as

possible. In homogeneous sets, the responses shared the prefix syllable whereas in heterogeneous sets they did not.

In the first experiment, opaque prefixed verbs whose bases are bound morphemes were compared with fully transparent prefixed verbs (e.g., *onthutsen* (*bewilder*) versus *ontkorsten* (*remove crust*)). The bound morphemes that were used are often referred to as "cranberry" morphemes (cf. Spencer 1991). A *cranberry* is a specific type of berry, so the formative *cran* must contribute to the meaning of the word. However, there are no other words which make use of this morpheme. Fully transparent prefixed verbs whose bases are free morphemes are prime candidates for decomposition, whereas opaque prefixed verbs whose bases are bound morphemes with no well-defined meaning of their own are prime candidates for storage as simple forms. According to WEAVER, however, morphemes are units in planning both transparent and opaque prefixed verbs. Thus, the model predicts no interaction between homogeneity and type of verb. Indeed, main effects of homogeneity and type of verb were obtained but absolutely no interaction.

In the second experiment, opaque prefixed verbs whose bases are bound morphemes were compared with opaque prefixed verbs whose bases are free morphemes (e.g., *onthutsen* versus *ontbijten* (*have breakfast*)). The free bases were independent words, but they did not preserve their meaning in the prefixed word. Since the free bases are words themselves, they must have their own form representation. In contrast, the bound bases are not independent words, so they do not need their own form representation. Nevertheless, according to WEAVER, both free and bound morphemes are units in planning these prefixed verbs, so both must have their own form representation. Thus, again, the model predicts no interaction. Indeed, main effects of homogeneity and type of verb were obtained but no interaction.

7. MORPHEME FREQUENCY

The new experiment reported below was designed to test predictions of WEAVER about the effect of morpheme frequency in producing polymorphemic words. According to the full listing hypothesis, Dutch compounds such as *schuimbad* (*bubble bath*) and *schoolbel* (*school bell*) are stored as simple forms: a single node for <schuimbad> and a single node for <schoolbel>. In contrast, according to WEAVER, these compounds are stored in a decomposed fashion: there are nodes for <schuim> and <bad> and nodes for <school> and <bel>. According to WEAVER, low-frequency morphemes (e.g., <schuim>) take longer to retrieve from memory than high-frequency morphemes (e.g., <school>), so the effect from response preparation should be larger for low-frequency morphemes (<schuim>) than for high-frequency ones (<school>). Thus, the model predicts a "reversed" frequency effect. Furthermore, WEAVER predicts that the frequency effect does not disappear with response repetition. If the effect is due to the suspension-resumption mechanism, then it should not depend on how often an item is produced in the experiment (as Jescheniak and Levelt 1994, observed for morphologically simple words). Note that frequency ef-

fects from <schuim> and <school> are not to be expected when *schuimbad* and *schoolbel* are stored as simple forms, that is, as <schuimbad> and <schoolbel>, respectively.

7.1. *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 (with levels Homogeneous and Heterogeneous). In the homogeneous condition, the response words shared the first morpheme, whereas in the heterogeneous condition there was no such overlap. Hereafter, I will refer to the critical part of a response as Fragment. In half of the homogeneous sets the shared morpheme was of high frequency, whereas in the other half of the homogeneous sets the morpheme was of low frequency. Hereafter, I will refer to this morphemic variable as Frequency (with levels High and Low). Word frequency was matched. The materials were obtained by an exhaustive search of the CELEX lexical database (Baayen, Piepenbrock, & van Rijn 1993). Tables 1 and 2 list the materials of the experiment.

Design. The experiment consisted of twelve experimental blocks administered consecutively. Half of the blocks was assigned a heterogeneous set and half a homogeneous set. The first six blocks in the experiment were made up by three homogeneous sets followed by three heterogeneous ones (participant groups A and B) or three heterogeneous sets followed by three homogeneous ones (participant groups C and D). The first morpheme of the responses was a high-frequency morpheme (groups A and C) or it was a low-frequency morpheme (groups B and D). In a block, each of the three pairs occurred randomly eight times. Hereafter, I will refer to the occurrence of a pair as Repetition (with levels 1 to 8). Thus, in total there were twenty-four trials within a block. A pair was not repeated on adjacent trials. In the next six blocks, the remaining six homogeneous and heterogeneous sets were presented. Again, the first morpheme of the responses was a high-frequency morpheme (groups B and D) or it was a low-frequency morpheme (groups A and C). The order of homogeneous and heterogeneous sets was counterbalanced across participants.

Procedure and apparatus. The participants 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 participant 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 twelve 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 participant indicated having studied the pairs sufficiently, the experimenter started the test phase. The

Low frequency				Approximate English translation		
douche	-	schuimbad	(9)	shower	-	bubble-bath
branding	-	schuimkop	(28)	breakers	-	spume
keuken	-	schuimspaan	(24)	kitchen	-	skimmer
		[419]				
western	-	postkoets	(29)	western	-	mail-coach
brieven	-	postzak	(12)	letters	-	mail-bag
trompet	-	posthoorn	(24)	trumpet	-	post-horn
		[167]				
andijvie	-	bloemkool	(94)	endive	-	cauliflower
receptie	-	bloemstuk	(34)	reception	-	bouquet
tuin	-	bloemperk	(50)	garden	-	flower-bed
		[634]				
		[407]	(34)			
High frequency				Approximate English translation		
zoemer	-	schoolbel	(11)	buzzer	-	school bell
redactie	-	schoolkrant	(27)	editors	-	school magazine
partijtje	-	schoolfeest	(13)	party	-	school-feast
		[8392]				
ergernis	-	punthoofd	(10)	annoyance	-	bonkers
kabouter	-	puntmuts	(21)	goblin	-	pointed cap
friet	-	puntzak	(26)	chips	-	cornet
		[5267]				
alcohol	-	bloedproef	(14)	alcohol	-	blood-test
moord	-	bloedspoor	(41)	murder	-	bloodstain
slagader	-	bloedvat	(176)	artery	-	blood-vessel
		[5142]				
		[6267]	(38)			

Table 1: Frequency per million in the CELEX database of the nominal compounds with the low-frequency and the high-frequency initial morphemes: between brackets the morpheme frequency and in parentheses the word frequency.

Low frequency					
Homogeneous			**Heterogeneous**		
douche	-	SCHUIMbad	douche	-	schuimbad
branding	-	SCHUIMkop	brieven	-	postzak
keuken	-	SCHUIMspaan	tuin	-	bloemperk
western	-	POSTkoets	branding	-	schuimkop
brieven	-	POSTzak	trompet	-	posthoorn
trompet	-	POSThoorn	andijvie	-	bloemkool
andijvie	-	BLOEMkool	keuken	-	schuimspaan
receptie	-	BLOEMstuk	western	-	postkoets
tuin	-	BLOEMperk	receptie	-	bloemstuk
High frequency					
Homogeneous			**Heterogeneous**		
zoemer	-	SCHOOLbel	zoemer	-	schoolbel
redactie	-	SCHOOLkrant	kabouter	-	puntmuts
partijtje	-	SCHOOLfeest	slagader	-	bloedvat
ergernis	-	PUNThoofd	redactie	-	schoolkrant
kabouter	-	PUNTmuts	friet	-	puntzak
friet	-	PUNTzak	alcohol	-	bloedproef
alcohol	-	BLOEDproef	partijtje	-	schoolfeest
moord	-	BLOEDspoor	ergernis	-	punthoofd
slagader	-	BLOEDvat	moord	-	bloedspoor

Table 2: Materials: Homogeneous and heterogeneous sets of nominal compounds with low-frequency or high-frequency initial morphemes.

structure of a trial was as follows. First, the participant 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 seconds. 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 participant's speech and tones indicating the onset of the prompt (1kHz) 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 participant might have produced a wrong response word. Second, the response might have exhibited a disfluency, that is, the participant stuttered, paused within the utterance, or repaired the utterance. Third, the voice key might have been triggered by a non-speech sound (noise in the environment or a smacking sound produced by the lips or tongue). Fourth, the participant 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, Frequency, Repetition, and Fragment as repeated measures factors.

Participants. The experiment was conducted with a group of twenty-four paid participants from the pool of the Max Planck Institute. All participants were native speakers of Dutch.

7.2. *Results and discussion*

Table 3 gives the mean production latencies for Context x Frequency x Repetition. A main effect of 89 ms was obtained for Context (means for the homogeneous and heterogeneous conditions were respectively 628 and 717 ms; $F_1(1, 20) = 78.53$, $MS_e = 58038$, $p < .001$; $F_2(1, 12) = 198.64$, $MS_e = 2897$, $p < .001$). Although overall the words with the low-frequency morphemes were produced slower than the words with the high-frequency morphemes, this difference was not reliable in the by-item analysis (means for the low-frequency and high-frequency sets were respectively 682 and 665 ms; $F_1(1, 20) = 7.54$, $MS_e = 23449$, $p < .01$; $F_2(1, 12) = 2.35$, $MS_e = 8460$, $p > .15$). There was a main effect of Repetition ($F_1(7, 140) = 26.77$, $MS_e = 9021$, $p < .001$; $F_2(7, 84) = 48.54$, $MS_e = 623$, $p < .001$). Most importantly, Context and Frequency interacted. The size of the effect of Context was (20 ms) larger for the words with the low-frequency morphemes than for the words with the high-fre-

quency morphemes (i.e., the effect sizes for Context were respectively 99 and 79 ms; by-subjects, $t(20) = 1.77$, $MS_e = 17831$, $p < .05$; by-items, $t(12) = 1.69$, $MS_e = 2897$, $p < .06$). This differential effect of frequency did not depend on Repetition ($F_1(7, 140) = 1.62$, $MS_e = 6404$, $p > .13$; $F_2(7, 84) = 1.11$, $MS_e = 1097$, $p > .36$). Thus, similar to what Jescheniak and Levelt (1994) observed for object naming, the frequency effect does not disappear with repetition. As Table 3 shows, the facilitory effect was numerically larger for the low-frequency condition than for the high-frequency condition for all repetitions except for the first and fifth repetition. There was no main effect of Fragment ($F_1(2, 40) = 2.66$, $MS_e = 16535$, $p > .08$; $F_2(2, 12) < 1$, $MS_e = 8460$, $p > .58$). There was no interaction between Fragment, Context, and Frequency ($F_1(2, 40) = 4.04$, $MS_e = 14566$, $p < .03$; $F_2(2, 12) = 2.42$, $MS_e = 2897$, $p > .13$) nor between Fragment, Context, Frequency, and Repetition ($F_1(14, 280) = 1.22$, $MS_e = 5296$, $p > .26$; $F_2(14, 84) < 1$, $MS_e = 1097$, $p > .75$).

	Frequency					
	Low			High		
Context	Hom	Het	Δ	Hom	Het	Δ
Repetition						
1	711	789	78	669	765	96
2	647	757	110	651	735	84
3	633	740	107	634	696	62
4	618	717	99	602	681	79
5	613	698	85	603	698	95
6	624	712	88	621	689	68
7	601	717	116	619	683	64
8	611	725	114	604	691	87
	632 (4.6)	731 (1.5)	99	625 (4.0)	704 (2.4)	79

Note: Hom = Homogeneous, Het = Heterogeneous

Table 3: Mean production latencies in milliseconds and error percentages (between parentheses) for Context x Frequency x Repetition.

The overall error rate (wrong responses and disfluencies) for the homogeneous and heterogeneous conditions was 4.3 and 1.9 percent, respectively. That is, on average,

in the whole experiment (i.e., on the 288 trials for a participant) a single participant made six errors in the homogeneous condition and three errors in the heterogeneous condition. The percentages for the conditions with the low-frequency and the high-frequency morphemes were 3.0 and 3.2. The total percentage of time-outs was 0.5 for the homogeneous condition and 0.9 for the heterogeneous condition, and the percentage of false triggering of the voice-key was respectively 0.6 and 1.2. The statistical analyses of the errors did not yield significant effects.

In summary, a facilitory effect is obtained from homogeneity of the initial morpheme of nominal compounds. The effect is larger when the morpheme is of low frequency (e.g., <schuim> in *schuimbad*) than when it is of high frequency (e.g., <school> in *schoolbel*): an effect of morpheme frequency on planning verbal responses. This differential effect of frequency is independent of repetition.

The outcomes support the idea that the component morphemes of compounds are planning units in speech production, confirming existing evidence from speech errors. If compounds are stored as simple forms (e.g., a node for <schuimbad> and a node for <schoolbel>), effects of the frequency of their constituent morphemes are not to be expected. Thus, the results support the decomposition assumption of WEAVER (i.e., nodes for <schuim>, <bad>, <school>, and <bel>). The finding that the differential effect of morpheme frequency is independent of repetition complies with the assumption that the locus of the effect is the lexeme level rather than the lemma level. Recall that the lemma-level effect of Jescheniak and Levelt disappeared over repetitions, whereas their lexeme-level effect did not. Note that the words with the high-frequency and low-frequency morphemes are produced equally often in the experiment, thus the production of the words in the experiments itself does not differentially affect their frequency of use. The outcomes of the experiment confirm the predictions of WEAVER.

8. CONCLUSIONS

This paper addressed the issue of whether the form lexicon underlying speech production contains morphologically decomposed entries. It reviewed existing evidence for morphological decomposition and reported a new experiment providing evidence for decomposition rather than full listing. In particular, the experiment tested predictions of the WEAVER model of word-form encoding in speech production, which assumes decomposed representations of lexical form. The predictions concerned the influence of morpheme frequency on planning verbal responses. The experimental outcomes confirmed the decomposition assumption. First, in the production of Dutch nominal compounds, both high-frequency and low-frequency morphemic constituents yield a facilitory effect in case of response homogeneity. Second, this facilitory effect is smaller for high-frequency constituents than for low-frequency constituents. Third, this differential effect of frequency does not disappear with response repetition. The latter suggests that the locus of the frequency effect is the form level rather than the lemma level.

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