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Phonology in the Production of Words

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Phonological Representations in the Mental Lexicon

How are words represented in the brain? Words have a meaning and a form, and presumably these two aspects of words are represented and processed separately in different areas of the brain (for a recent overview see Indefrey and Levelt, 2004). For instance, each act of speech production is planned in advance and starts with the intention to talk about a specific 'meaning' which is to be conveyed to the interlocutor(s). Therefore, the first step in speech production is called conceptualization (Levelt, 1989). In this phase, the content of an utterance is represented as prelinguistic units or concepts. During the next step, called formalization, concepts become lexicalized, i.e., lexical entries corresponding to the concepts are retrieved. Formalization can be divided into two processes, namely, grammatical encoding and phonological encoding (Levelt *et al.*, 1999). This division is based on empirical data, such as speech errors. Garrett (1975) already observed that there are at least two categories of exchange errors, i.e., word exchanges and segment (phoneme) exchanges. An example of a word exchange is ***laboratory*** *in your own* ***computer*** (Fromkin, 1971); *laboratory* and *computer* belong to different syntactic phrases, but they are of the same syntactic word class, i.e., nouns. Segment or phoneme exchanges, in contrast, typically result from the same syntactic phrase, but from words of different syntactic word classes, e.g., *our* ***q****ueer* ***d****ean* (instead of *our* ***d****ear* ***q****ueen*; an original spoonerism). This pattern of word and segment exchanges can be explained by ssuming that word exchanges occur during grammatical encoding, whereas segment exchanges occur during subsequent phonological encoding. During grammatical encoding the syntactic structure of an utterance is specified including the syntactic word class of an individual word, but not its phonological form. That is why words of the same word class are exchanged, no matter what their phonological make up is. In contrast, during phonological encoding the words of an utterance have already been selected, i.e., their syntactic word class information can no longer influence the planning process, but their phonological form is still to be specified. During this specification segments or phonemes from adjacent words can accidentally become active at the same time, and then they can be exchanged and result in a sound error.

In the meantime, on-line experimental evidence for the division between grammatical and phonological encoding has been obtained. Schriefers *et al.* (1990) asked Dutch participants in the laboratory to name pictures while presenting them with auditory distracter words. When the distracter words were semantically, i.e., categorically, related to the target picture name (e.g., *gieter* 'watering can'), participants were slower to name the picture of a rake (*hark*) compared to an unrelated distracter word (e.g., *bel* 'bell') (see Figures 1–3). However, this happened only when the distracter words were presented slightly before picture onset or simultaneously with the picture onset (see Figure 4). When the distracter words were phonologically related to the picture name (e.g., *harp* 'harp'), however, the naming of *hark* was faster than in the unrelated control condition (see Figures 5–7). However, this effect disappeared when the phonologically related distracter words were presented before picture onset (see Figure 8).

The received account for the semantic interference effect (*hark*–*gieter*) is that the lexical entry *gieter* does

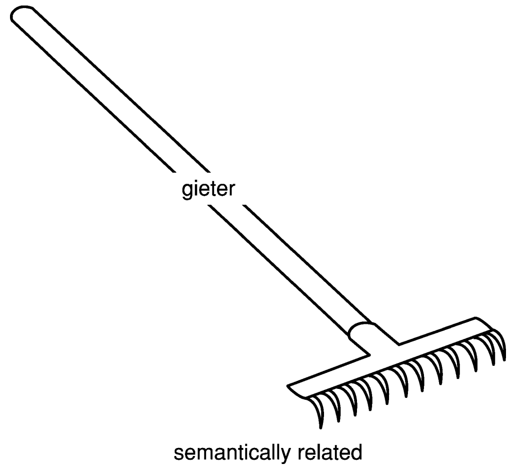

Figure 1 Picture naming with a semantically related distracter word. Participants' task is to name the picture and ignore the word. It is known that such a situation yields Strooplike interference, i.e., participants are influenced by the distracter word when naming the picture.

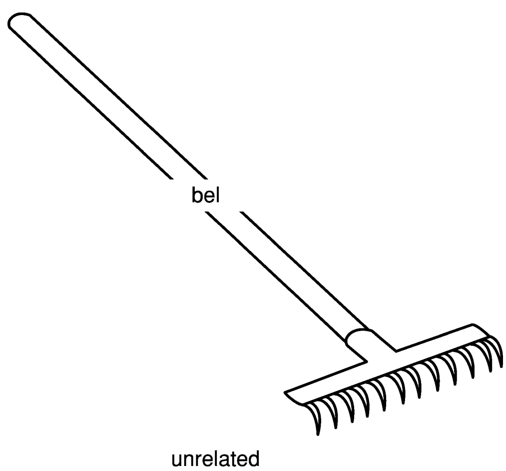

Figure 2 Picture naming with an unrelated distracter word.

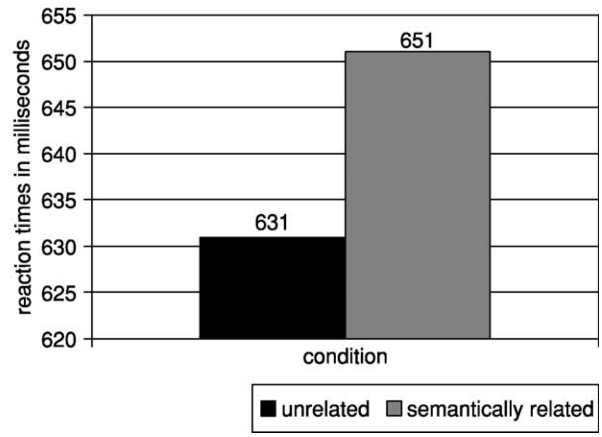

Figure 3 The semantic interference effect in speech production. Naming latencies are slower when the distracter word is semantically related to the picture than when it is unrelated. The results are taken from a study by Schriefers *et al.* (1990).

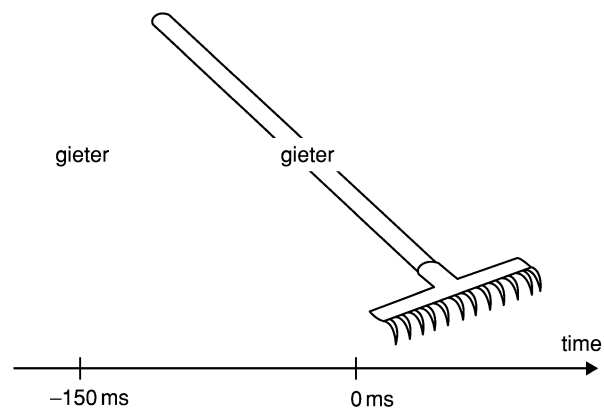

Figure 4 The time course of semantic interference in speech production. The effect occurs only when the distracter word is presented slightly (e.g., –150 ms) before picture onset or simultaneously with the picture.

not only receive activation from the auditory presentation of the distracter word, but also – via the conceptual network 'garden utilities' – from the picture of the *hark* ('rake') due to the fact that there are connections between conceptually similar entries. Therefore, *gieter* ('watering can') is a stronger lexical competitor than the unrelated distracter *bel* ('bell'), which does not receive activation from the picture of the rake (see also Levelt *et al.*, 1999: 10–11). The phonological facilitation is accounted for by assuming that the phonological distracter *harp* preactivates segments (phonemes) in the production network. The segments that are shared between distracter and target (/h/, /a/, /r/) can be selected faster when the target picture name *hark* is phonologically encoded. One can infer from this pattern that semantic-categorically related distracters have an influence on the speech production process at an earlier point in time, namely during lexical selection, than phonologically related distracter words, which only show an influence during phonological encoding (see Figure 9).

This article is about phonology in the production of words. A model of phonological encoding is provided by Levelt and Wheeldon (1994) and has been further developed since then (see Figure 10). This model describes word form encoding processes that follow the selection of a word from the mental lexicon. Once a word has been selected from the mental lexicon, it has to be encoded in a form that can finally be used to control the neuromuscular commands necessary for the execution of articulatory movements (see Guenther, 2003 for a recent overview). When accessing a word's form for phonological encoding, speakers retrieve segmental and metrical information.

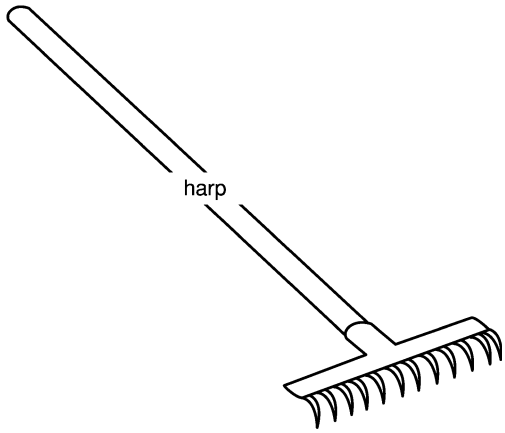

Figure 5 Picture naming with a phonologically related distracter word.

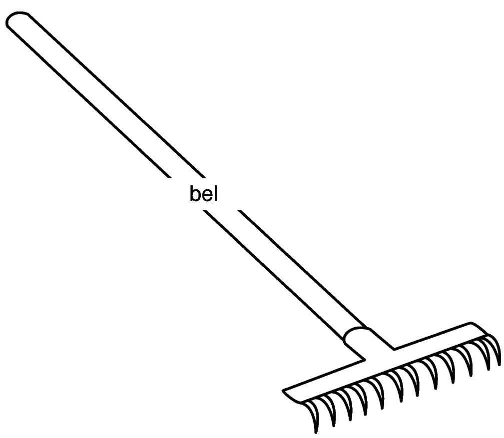

Figure 6 Picture naming with an unrelated distracter word.

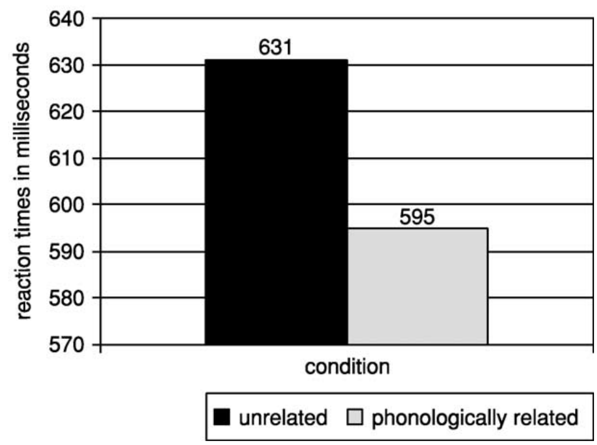

Figure 7 The phonological facilitation effect in speech production. Naming latencies are faster when the distracter word is phonologically related to the picture than when it is unrelated. The results are taken from a study by Schriefers *et al.* (1990).

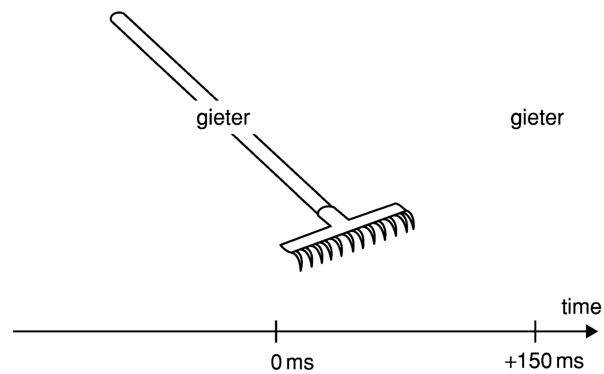

Figure 8 The time course of phonological facilitation in speech production. The effect occurs only when the distracter word is presented simultaneously with the picture or slightly (e.g., +150 ms) later than picture onset.

During segmental encoding, the segments (phonemes) of a word and their order have to be retrieved. For the word *lepel* 'spoon' this would be the segments /l/$_1$, /e/$_2$, /p/$_3$, /ə/$_4$, /l/$_5$. During metrical retrieval, a metrical frame has to be retrieved, i.e., the number of syllables and the location of the lexical stress. For the example *lepel*, the metrical frame would include two syllable slots, the first of which bears lexical stress (e.g., '_ _). Furthermore, the syllable or consonant–vowel (CV) structure of the individual syllables of the word may be retrieved (Dell, 1988; but see Roelofs and Meyer, 1998). Once the segmental and the metrical information has been retrieved, it is combined during a process called segment-to-frame association. During this process, the previously retrieved segments are combined from word beginning to end with their corresponding metrical frame. The resulting phonological string is syllabified according to universal and language-specific syllabification rules. A fully prosodified phonological word is generated, which forms the basis for the activation of syllables in a mental syllabary (Levelt and Wheeldon, 1994). Presumably, the units in the syllabary can be conceived of as precompiled articulatory motor programs of syllabic size. These motor programs may be represented in terms of gestural scores, i.e., a phonetic plan that specifies the relevant articulatory gestures and their relative timing (see Goldstein and Fowler, 2003 for a review). The final step includes the execution of these gestures by the articulatory apparatus. This results in overtly produced speech (see Figure 11).

One puzzling feature of this mechanism is why segments and metrical frame are retrieved independently from memory when both types of information are reunified slightly later. However, while this may seem puzzling when considering single, isolated word production, it is not when the production of words in context is taken into account. For instance, syllabification does not respect lexical boundaries since the domain of syllabification is the phonological word

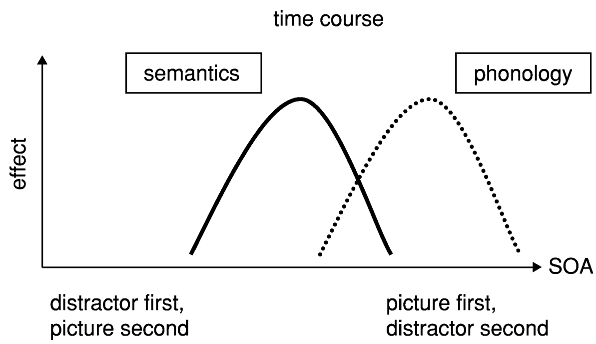

Figure 9 Schematic illustration of the time course of semantic and phonological effects in speech production. SOA = stimulus onset asynchrony.

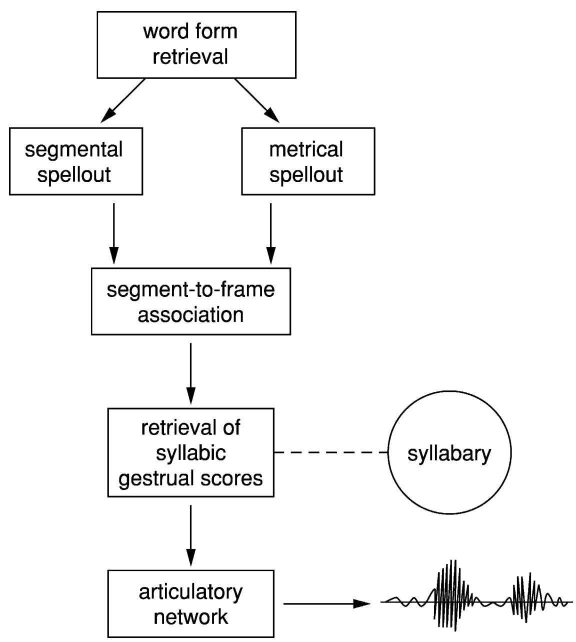

Figure 10 A model of phonological encoding (after Levelt and Wheeldon, 1994).

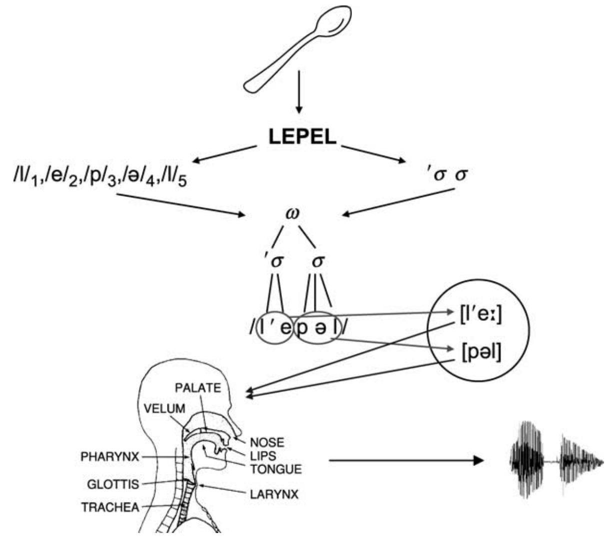

Figure 11 Example of the phonological encoding of a picture name (animated with sound).

(not the lexical word). Let us take the example of the verb *to type*. *Type* is a monosyllabic CVC word. Now consider the words *ty.pist* (someone who types; dots indicate syllable boundaries), *ty.ping* (the gerund), or the phrase *ty.pe it*. In all of these examples, the coda /p/ of *type* /taɪp/ becomes the onset of a second syllable. In the example *ty.pe it*, it even straddles the lexical boundary between 'type' and 'it.' Therefore, it is important to bear in mind that segments (phonemes) are not inserted into a lexical word frame, but into a phonological word frame. The phonological word, however, is a context-dependent unit. It can solely consist of the lexical word 'type' as in 'type faster,' or unstressed function words such as 'it' can cliticize to it as in 'type it faster,' yielding *ty.pe it* /taɪ.pɪt/. A corollary of context-dependent syllabification in speech production is that it would not make much sense to store syllable boundaries with the word forms in the mental lexicon because syllable boundaries change as a function of the phonological context. The so-called syllable position constraint observed in sound errors (i.e., onsets exchange with onsets, nuclei with nuclei, etc.) can probably not hold as an argument for stored syllable frames because it may just be a reflection of the general tendency of segments to interact with phonemically similar segments. Therefore, it makes more sense to postulate that syllables are not stored with their lexical entries (Levelt *et al.*, 1999). Rather, syllable boundaries will be generated on-line during the construction of phonological words to yield maximally pronounceable syllables. This architecture lends maximal flexibility to the speech production system in all possible contexts.

Segmental Encoding

Speech error research has been an important source of information for the understanding of segmental encoding (Shattuck-Hufnagel, 1979 for an overview). The vast majority of sound errors are single-segment errors, but sometimes also consonant clusters get substituted, deleted, shifted, or exchanged. Most often, the word onset is involved in a sound error, although sometimes also nuclei (*beef* ***needle*** instead of *beef noodle)* or codas (*go****d*** *to* ***seen*** instead of *gone to seed*) form part of an error. This points to the general importance of the word onset in phonological encoding (see Schiller, 2004 for more details). Some errors suggest the involvement of phonological features in planning phonological words, e.g., ***glear plue*** *sky* (Fromkin, 1971). In this latter example, it seems as if only the feature [VOICE] changed position although two independent segmental sound errors (i.e., /k/ → /g/ and /b/ → /p/) cannot be excluded, either. In fact, often the target and the error only differ in one single phonological feature, and there is a tendency for more specified segments to substitute for less specified features, e.g., *documentation* → *documendation*; /t/ [−VOICE] → /d/ [+VOICE] (Stemberger, 1991). The reason for this 'addition bias' is not entirely clear. One important question which featural errors raise concerns the representation of segments during on-line processing: are segments represented as phonemic units or as bundles of phonological features?

In speech production, metalinguistic evidence (backward talking, language games, etc.) as well as speech errors (the vast majority of the phonological slips concern a single phoneme) suggest that the segment is the smallest unit of speech planning. However, as mentioned above, there are some speech errors which might imply a representation in terms of phonological features. In Levelt *et al.*'s (1999) model, the features of the segments in a syllable were accessed in parallel. Moreover, Roelofs (1999) showed that a difference in a single phonological feature (e.g., ***been*** 'leg' [+VOICE], ***bos*** 'forest' [+VOICE], ***pet*** 'cap' [−VOICE]) is enough to spoil the so-called preparation effect (see below). This suggests that segments are planning units independent of their phonological features. However, this finding does not exclude that features may play a role in planning a word form. In fact, there are instances when subphonemic specification is required in speech production (e.g., *I scream* and *ice cream* are segmentally identical, i.e., /aɪ.skrim/), and it is as yet not clear how exactly subphonemic details can form part of the theory (see also McQueen *et al.*, 2003).

Time Course of Segmental Processing

One important question in word processing is the time course of the processes involved. For instance, does semantic processing precede phonological processing in speech production or do these two processes occur in parallel? Similarly, are the segments of a word encoded one after the other or are they encoded in parallel? It was argued above on the basis of empirical evidence (e.g., sound errors) as well as on theoretical grounds that word forms are planned in terms of abstract units called segments or phonemes. Meyer (1990, 1991) had participants produce sets of words that either overlapped in the onset phoneme (***h****ut* 'tent,' ***h****eks* 'witch,' ***h****iel* 'heel'), or in the first two phonemes (***ha****mer* 'hammer,' ***ha****ring* 'herring,' ***ha****gel* 'hail'), or in the first three phonemes (***hav****er* 'oats,' ***hav****en* 'haven,' ***hav****ik* 'hawk'), or in the final phonemes (*h****aard*** 'stove,' *p****aard*** 'horse,' *k****aard*** 'map'). These were the so-called homogeneous conditions, which were compared to so-called heterogeneous conditions in which the words did not overlap at all (*hut* 'tent,' *dans* 'ballet,' *klip* 'cliff'). Reaction times were found to be faster when the beginning of the target words could be planned in advance but not when the final part could be prepared. The magnitude of this preparation effect depended on the size of the string that could be prepared, i.e., the more phonemes overlapped among the words within a set, the larger the preparation effect. Importantly, this was only true for beginning-overlap, but not for end-overlap, suggesting that the phonological planning of words is strictly sequential, i.e., proceeding in a left-to-right fashion from the beginning of words to their end. When the onset phoneme is not known, nothing can be prepared.

Wheeldon and Levelt (1995) provided additional evidence for the incremental nature of segmental phonological encoding. They required bilingual Dutch–English participants to internally generate Dutch translations to English prompt words, which were displayed via headphones. However, participants did not overtly produce the Dutch words but self-monitored them internally for previously specified segments. For example, participants would hear the English prompt word *hitchhiker* and were asked to press a button on a button box in front of them if the Dutch translation (*lifter*) contained the phoneme /t/. Thus, for *hitchhiker* participants would press the button as fast as possible, whereas for *cream cheese* (*roomkaas*) they would not. The button press latencies varied as a function of the target phoneme in the translation word. That is, participants were faster when the prespecified phoneme (e.g., /t/) was in onset position (e.g., *garden wall–tuinmuur*) than when it occurred in the middle (e.g., *hitchhiker–lifter*) or at the end of the translation word (e.g., *napkin–servet*). The earlier the target phoneme occurred in the Dutch word, the shorter the decision latencies (see Figure 12). These data have been interpreted as support for the claim of rightward incremental encoding. Furthermore, these effects have been localized at the phonological word level, i.e., when segments and metrical frames are combined because metrical stress location influences the effect. Moreover, Wheeldon and Levelt (1995) observed a significant increase in monitoring times when two segments were separated by a syllable boundary. One possibility is that the monitoring difference between the target segments at the syllable boundary (e.g., *fiet.ser* vs. *lif.ter*) might be due to the existence of a marked syllable boundary or a syllabification process that slows down the encoding of the second syllable.

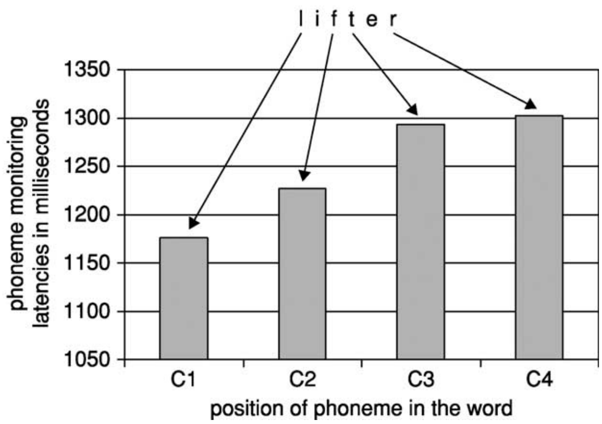

Figure 12 Mean reaction times of phoneme monitoring as a function of the position of the target phoneme in the word form. The results are taken from a study by Wheeldon and Levelt (1995).

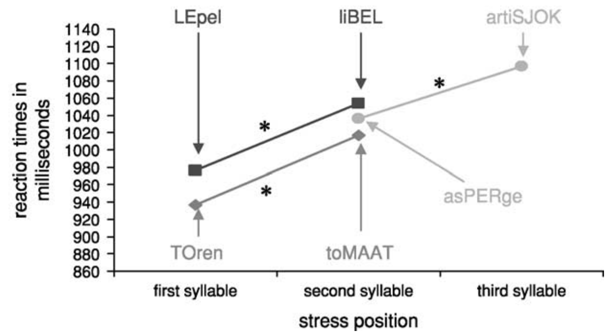

Figure 13 Summary of the stress-monitoring latencies. Depicted are the reaction times of three experiments, two with disyllabic words (example words *LEpel–liBEL* and *TOren–toMAAT*) and one with trisyllabic words (example words *asPERge–artiSJOK*) as a function of the position of the lexical stress in the picture name. The results are taken from a study by Schiller *et al.* (2005).

Metrical Encoding

Roelofs and Meyer (1998) investigated how much information about the metrical structure of words is stored in memory. Possible candidates are lexical stress, number of syllables, and syllable structure. In one experiment, for instance, they compared the production latencies for sets of homogeneous disyllabic words such as *ma.NIER* ('manner'; capital letters indicate stressed syllables), *ma.TRAS* ('mattress'), and *ma.KREEL* ('mackerel') with sets including words with a variable number of syllables such as *ma.JOOR* ('major'), *ma.TE.rie* ('matter'), and *ma.LA.ri.a* ('malaria'). Lexical stress was kept constant (always on the second syllable). Relative to a heterogeneous control condition, there was strong and reliable facilitation for the disyllabic sets but not for the sets with variable numbers of syllables. This showed that the number of syllables of a word must be known to the phonological encoding system. Hence, this information must be part of the metrical representation of words.

Similarly, the production of sets of homogeneous trisyllabic words with constant stress (e.g., *ma.RI.ne* 'navy,' *ma.TE.rie* 'matter,' *ma.LAI.se* 'depression,' *ma.DON.na* 'madonna') and variable stress (e.g., *ma.RI.ne* 'navy,' *ma.nus.CRIPT* 'manuscript,' *ma.TE.rie* 'matter,' *ma.de.LIEF* 'daisy') was measured and compared to the corresponding heterogeneous sets. Again, facilitation was obtained for the constant sets but not for the variable ones. Therefore, one can conclude that the availability of stress information is indispensable for planning of polysyllabic words – at least when stress is in nondefault position. However, CV structure did not yield an effect. When the production latencies for words with a constant CV structure (e.g., *bres* 'breach,' *bril* 'glasses,' *brok* 'piece,' *brug* 'bridge'; all CCVC) were compared to words with a variable CV structure (e.g., *brij* 'porridge,' CCVV; *brief* 'letter,' CCVVC; *bron* 'source,' CCVC; *brand* 'fire,' CCVCC), relative to the corresponding heterogeneous conditions, no difference was found, suggesting that the metrical structure speakers retrieve does not contain information about the CV or syllable structure of a word.

Time Course of Metrical Processing

To investigate the time course of metrical processing, Schiller and colleagues employed a tacit naming task and asked participants to decide whether the disyllabic name of a visually presented picture had initial or final stress. Their hypothesis was that if metrical encoding is a parallel process, then there should not be any differences between the decision latencies for initial and final stress. If, however, metrical encoding is also a rightward incremental process – just like segmental encoding – then decision latencies for picture names with initial stress should be faster than for picture names with final stress. The latter turned out to be the case (Schiller *et al.*, 2005). However, Dutch – like other Germanic languages – has a strong preference for initial stress. More than 90% of the words occurring in Dutch have stress on the first syllable. Therefore, this effect might have been due to a default strategy. However, when pictures with trisyllabic names were tested, participants were still faster to decide that a picture name had penultimate stress (e.g., *asPERge* 'asparagus') than that it had final stress (e.g., *artiSJOK* 'artichoke'). This result suggests that metrical encoding proceeds from the beginning to the end of words, just like segmental encoding (see Figure 13).

Syllables

The contribution of the syllable in the speech production process is quite controversial. Studies by Ferrand *et al*. (1996) reported a syllable-priming effect in French speech production. The visually masked prime *ca* primed the naming of *ca.rotte* better than the naming of *car.table*. Similarly, the prime *car* primed the naming of *car.table* better than the naming of *ca.rotte* (see Figure 14). This effect is a production equivalent of the syllabic effect reported by Mehler *et al*. (1981). Ferrand *et al*. (1996) concluded that the output phonology must be syllabically structured since the effect disappears in a task that does not make a phonological representation necessary, such as a lexical decision task. Furthermore, Ferrand *et al*. (1996) argued that their data are compatible with Levelt's idea of a mental syllabary, i.e., a library of syllable-sized motor programs. Interestingly, Ferrand *et al*. (1997) also report a syllable-priming effect for English. This is surprising considering the fact that Cutler *et al*. (1983) could not get a syllabic effect for English speech perception.

However, when Schiller (1998) tried to replicate the syllabic effects in Dutch speech production, he failed to find a syllabic effect. Instead, what he obtained was a clear segmental overlap effect, i.e., the more overlap between prime and target picture name, the faster the naming latencies. That is, the prime *kan* yielded not only faster responses than *ka* for the picture of a pulpit (*kan.sel*) but also for the picture of a canoe (*ka.no*) (see Figure 15).

Similar results were obtained in the auditory modality, i.e., presenting either /ro/ or /rok/ when Dutch participants were requested to produce either *ro.ken* ('to smoke') or *rook.te* ('smoked'). In fact, in the auditory modality also a segmental overlap effect was obtained, i.e., /rok/ was a better prime than /ro/ independent of the target. The failure to find a syllable-priming effect in Dutch is in agreement with the statement that syllables are never retrieved during phonological encoding (Levelt *et al*., 1999). The syllable-priming effect found by Ferrand *et al*. (1996) in French can be accounted for by assuming that the segments in the prime are coded with their corresponding syllable structure information. For instance, the prime *pal* preactivates segments specified for syllable position in the perceptual network, e.g., p_{onset}, a_{nucleus}, and l_{coda}. Active phonological segments in the perceptual network can directly affect the corresponding segment nodes in the production lexicon. Therefore, the prime matches with the target *pal.mier*, but not with *pa.lace* because the /l/ in *pal* is specified for coda and not for onset.

The segmental overlap effect is not restricted to Dutch. When Schiller (2000) tried to replicate the Ferrand *et al*. (1997) results for English with better-controlled material, no syllabic effect was obtained but a segmental overlap effect was. These English data are interesting because in English there is phonological equivalence between corresponding syllable structures. For example, *pi* /paɪ/ matches phonologically the first syllable in *pilot* but not in *pillow*, and *pil* /pɪl/ matches phonologically the first syllable in *pillow* but not in *pilot*. Nevertheless, the prime *pil* yielded faster responses than *pi* for both *pilot* and *pillow* (see Figure 16).

Either the contribution of vowels is less important in segmental priming or consonants and vowels have different time courses of activation (Berent and Perfetti, 1995), consonants being faster than vowels

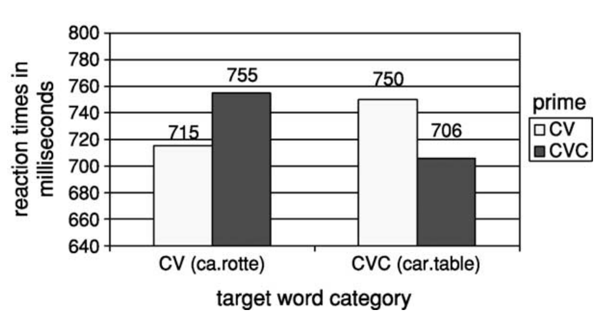

Figure 14 Mean reaction times (picture-naming latencies) per prime and target category in the Ferrand *et al*. (1996) study.

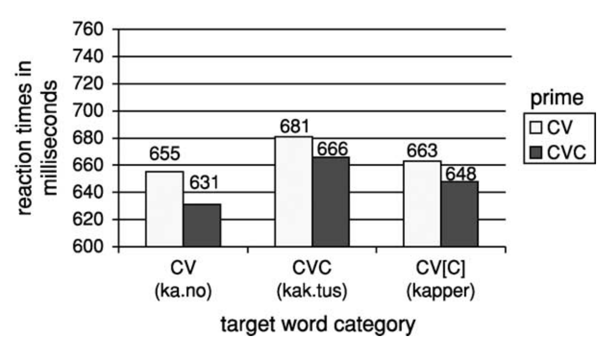

Figure 15 Mean reaction times (picture-naming latencies) per prime and target category in the Schiller (1998) study.

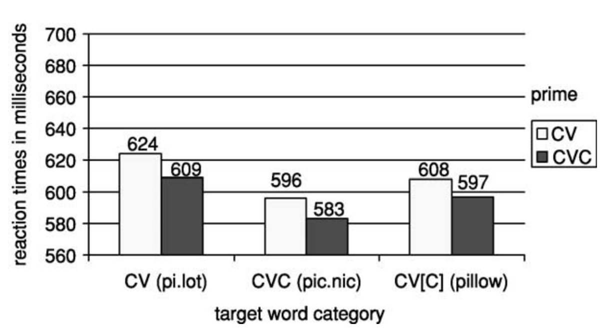

Figure 16 Mean reaction times (picture-naming latencies) per prime and target category in the Schiller (2000) study.

and therefore more effective. Further testing revealed that there is no syllable effect in Spanish, but a small segmental overlap effect (Schiller *et al.*, 2002), and no syllabic effect in French when a larger set of materials is tested (Schiller *et al.*, 2002). Taken together, these results support the idea that syllables are not retrieved, but created on-line during phonological encoding.

Mental Syllabary

The existence of a mental syllabary is a hotly debated topic. The original idea for a 'library of articulatory routines' comes from work on speech errors (Crompton, 1981; Levelt, 1989). The idea was that precompiled motor programs of syllable size could help reduce the computational load during speech production if they form the basic units of articulatory programming. This idea is attractive from a lexicostatistical point of view since the majority of the speech in Dutch (about 85%) can be produced with a minority of the Dutch syllables (only 5% of all Dutch syllables). Therefore, Levelt and Wheeldon (1994) tested this idea in an experiment comparing the production latencies of words differing in syllable frequencies. For instance, there were words in the experiment that consisted of high-frequency syllables (e.g., *bo.ter* 'butter') and words that were made up from low-frequency syllables (e.g., *gi.raf* 'giraffe') while word frequency was controlled. Results showed that words with high-frequency syllables were named significantly faster than words with low-frequency syllables, independent of word frequency. Levelt and Wheeldon (1994) took this finding as evidence for a separate store from which syllabic units can be recruited during speech production. However, syllable frequency correlates highly with segment or phoneme frequency. Therefore, the effect reported by Levelt and Wheeldon (1994) could as well be attributed to segment frequency. When segment frequency was controlled, a small set of awkward word stimuli remained and the syllable frequency effect disappeared.

Although syllables cannot be primed in Dutch, Cholin *et al.* (2004) found that syllable structure can be prepared in the planning of speech production. Syllables probably emerge at the interface between phonological and phonetic encoding. In a follow-up study, the same authors found significant syllable frequency effects in pseudoword production when segment frequency was controlled for (Cholin *et al.*, in press). This latest result strongly supports the notion of a mental syllabary that mediates between abstract phonological syllables and phonetic syllables, which are conceived of as precompiled gestural scores to control the execution of an articulatory motor program.

Summary and Conclusion

In this article, I described the role of phonology in the production of words. A model of phonological encoding was described. Certain aspects of this model, such as the role of segments and metrical frames, were discussed in more detail. It was argued on the basis of speech error and reaction time data that segments rather than phonological features play a role in production planning, while more subphonemic detail is necessary to account for the speech comprehension data. Furthermore, the nature of metrical frames was described and it was argued that segments as well as lexical stress are encoded rightward incrementally. Finally, the role of syllables in speech production was sketched and the role of a mental syllabary was discussed. It is concluded that more research on phonological processing is necessary to specify aspects of the model that are currently underspecified.

See also: Dutch; English in the Present Day (since ca. 1900); Phonology–Phonetics Interface; Speech Errors as Evidence in Phonology; Speech Errors: Psycholinguistic Approach; Speech Production; Spoken Language Production: Psycholinguistic Approach; Syllable: Phonology; Word Stress.

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Phonology: Optimality Theory

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Introduction

Optimality theory, introduced in the early 1990s (Prince and Smolensky, 1993; McCarthy and Prince, 1993a,b), offers an extremely simple formal model of language, with far-reaching implications for how language works. The formal component of each grammar consists of a ranked ordering of a universal set of constraints; this ordering is used to identify the best pairing between a given input and all potential outputs. Languages differ not by the constraints used, but by the ranking used – the constraints are universal. Depending on where a particular constraint falls in the constraint hierarchy of the language determines how roundly violated that constraint will be, because all constraints are violable. The ranking determines which violations matter for which input–output mappings (for overviews, see Archangeli and Langendoen, 1997; Kager, 1999; McCarthy, 2002, 2004).

During the 1970s and into the 1980s, phonological research centered on phonological representations. As representations were better understood, the rules relating those representations to each other seemed to