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Stages of lexical access in language production*

Gary S. Dell
Department of Psychology, University of Illinois, Urbana, IL 61801, USA

Padraig G. O'Seaghdha
Department of Psychology, Lehigh University, Bethlehem, PA 18015, USA

Abstract

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We describe two primary stages in the top-down process of lexical access in production, a stage of lemma access in which words are retrieved as syntactic–semantic entities, and a stage of phonological access in which the forms of the words are fleshed out. We suggest a reconciliation of modular and interactive accounts of these stages whereby modularity is traceable to the action of discrete linguistic rule systems, but interaction arises in the lexical network on which these rules operate. We also discuss the time-course of lexical access in multi-word utterances. We report some initial production priming *explorations that support the hypothesis that lemmas are buffered in longer utterances before they are phonologically specified. Because such techniques provide a relatively direct way of assessing activation at the primary stages of lexical access they are an important new resource for the study of language production.*

Introduction

Many of the current controversies in psycholinguistics concern the temporal properties of language processing. For example, no one disputes that prior context is used in deciding whether a homophone such as /*roz*/ is a noun or a verb, but

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there is heated debate about when this context is used (see, for example, Burgess, Tanenhaus, & Seidenberg, 1989; Glucksberg, Kreuz, & Rho, 1986; Tabossi, 1988; Van Petten & Kutas, 1987). In general, much of what has been called the modularity question in language processing concerns the time-course of the access and use of various kinds of linguistic and contextual information (Fodor, 1983; Tanenhaus, Dell, & Carlson, 1987). The time-course issue also dominates discussion of the topic of this paper: lexical access in language production. There is little doubt that lexical access involves a mapping between a conceptual representation and a word's phonological form. Similarly, it is universally acknowledged that pragmatic, semantic, syntactic, and phonological information all play a role in achieving this mapping. But difficult questions concerning the time-course of the mapping process remain. When are the various types of linguistic information used? Is their use organized into temporally distinct stages? Or do the various types of information exert their influence throughout the process of mapping from meaning to sound?

Our paper focuses on two aspects of the time-course of access, which we call the *discreteness* and *advance-planning* questions. Both of these questions address the temporal properties of the access of semantic and phonological information during lexical access. The discreteness issue turns on whether semantic information is segregated from phonological information, semantic information being accessed and used at an earlier stage of lexical access than phonological information. The advance-planning question arises in the case of multi-word utterances. At what point is lexical access completed for upcoming words in an utterance? More specifically, how far does planning of the semantic aspect of upcoming words lead that of the phonological aspect?

In order to distinguish the discreteness and advance-planning questions more precisely, we begin with the working assumption that lexical access in production can be roughly divided into two steps. In the first step, *lemma access*, a mapping is achieved between a concept-to-be-lexicalized and a *lemma*, an abstract symbol representing the selected word as a semantic–syntactic entity. In the second step, *phonological access*, the lemma is translated into the word's phonological form. This two-step conception of lexical access has long been a part of language production theory. It has been used to interpret data from the study of normal speech errors (e.g., Dell, 1986; Fromkin, 1971; Garrett, 1975), aphasia (e.g., Butterworth, 1989; Saffran, Schwartz, & Marin, 1980) and a variety of experimental paradigms (e.g., Bock, 1987; Kempen & Huijbers, 1983; Levelt & Maassen, 1981; Levelt et al., 1991; Schriefers, Meyer, & Levelt, 1990).

The discreteness question concerns the nature and time-course of these two steps. The modular two-step hypothesis (Butterworth, 1989; Levelt et al., 1991; Schriefers et al., 1990) contends that lemma and phonological access are non-overlapping stages that operate on different inputs. In particular, semantic but not phonological information is active up to the point of lemma access, but the reverse is true during phonological access. A contrasting view, the interactive two-step hypothesis (Dell, 1986; Harley, 1984; Martin, Weisberg, & Saffran, 1989; Stemberger, 1985) conceives of lexical access in more continuous terms. Activation is predominantly semantic during lemma access, and activation is predominantly phonological during phonological access, but there is some activation of phonological information during lemma access, and some activation of semantic information during phonological access. Typically, this interactive view is implemented through spreading activation.

The distinction between lemma access and phonological access also informs the advance-planning question. Suppose that one were planning a three-word utterance. Let us refer to the lemma of word *n* as L(*n*) and to its phonological form as P(*n*). The advance-planning question concerns the order of accessing lemmas and phonological forms. One possibility, which we call the lemma buffering hypothesis, states that several lemmas are selected before the corresponding phonological forms are filled in. In the simplest version of lemma buffering, the order of the steps might be: //L(1) L(2) L(3) / P(1) P(2) P(3)//. That is, the lemmas are all selected first, and the phonological forms are filled in later (see Kempen & Huijbers, 1983). However, because there must be a limit on the number of lemmas that can be buffered, a more plausible version of the lemma buffering hypothesis is that the size of the buffers is related to sentence structure. So, if there were a major structural boundary between words two and three, the step sequence might be: //L(1) L(2) / P(1) P(2) // L(3) / P(3)//. The most distinct alternative to lemma buffering is a word-by-word view in which the phonological form is retrieved sequentially for each lemma: //L(1) / P(1) // L(2) / P(2) // L(3) / P(3)//. Note that although lemma buffering implies the truth of the two-step hypothesis, it is neutral on the question of whether these steps are modular or interactive.

In the remainder of the paper we review the evidence on the discreteness and advance-planning questions, and introduce some new experiments of our own. We turn first to the discreteness question, which has recently been spotlighted by Schriefers et al. (1990) and Levelt et al. (1991), who used priming techniques to track the time-course of lexical access for single words.

The discreteness question

Recently, production researchers have turned to the priming techniques that have been so widely and successfully used to study language comprehension (Bock, 1986, 1987; Levelt et al., 1991; O'Seaghdha & Dell, 1991a, 1991b; O'Seaghdha, Dell, Peterson, & Juliano, in press; Schriefers et al., 1990). In doing so, they have sometimes devised new procedures and sometimes exploited the productive aspects of existing techniques. Thus, Schriefers et al. recently adapted a *picture* *interference* paradigm (e.g., Glaser & Dunglehoff, 1984; Lupker, 1979) to study the question of the modularity of lexical access in production.

The standard picture interference paradigm involves superimposing an interfering word on a picture-to-be-named. It is called an interference paradigm because presentation of a word usually interferes with picture naming relative to a condition in which the picture alone is presented. Schriefers et al. made one significant change to the standard procedure. Because they were interested in phonological rather than in graphemic effects, they presented the words auditorily. In their experiments, subjects named pictures in the presence of semantically or phonologically related spoken words, or in a variety of control conditions. To examine the time-course of semantic and phonological access, the relative onsets of pictures and words were varied such that the word onset preceded the picture by 150 ms, coincided with it, or lagged it by 150 ms.

Schriefers et al. found evidence of semantic interference, relative to unrelated control words, when the words preceded the pictures, but not in the two later word presentation conditions. In contrast, in the case of phonologically related words, they found facilitation relative to the unrelated condition for the two later word onset conditions, but no effect when the word onset preceded the picture. Thus, they were apparently able to distinguish rather elegantly between an early phase of semantic activation and a later phase of phonological activation.

The presence of semantic interference when the word preceded the picture is in agreement with previous findings with visual word presentation (e.g., Glaser & Dunglehoff, 1984), and thus Schriefers et al.'s conclusions concerning the time-course of semantic activation are likely correct. The mechanism leading to the facilitatory phonological effects is less clear. One possibility derives from the fact that the related words shared initial segments with the picture names. In the late presentation conditions, the conflicting final segments of the interfering words may not have had time to influence processing. As a result, the phonologically related condition may be functionally like an identity priming condition. Alternatively, the effects could be due to some processes that occur after phonological access, such as the kind of auditory–articulatory interactions described by Gordon and Meyer (1984). However, although we are less persuaded by the phonological time-course results than by the semantic ones, the results of Schriefers et al. are generally in accord with a modular two-step view of access.

Some additional evidence which may clarify the nature of phonological priming effects was provided by Levelt et al. (1991), who employed a related but different procedure. As in Schriefers et al., the primary task was to name pictures of concrete objects, and verbal materials were also presented auditorily. However, the auditory items, which occurred on less than one-third of the trials, were word or non-word targets requiring a lexical decision response. On most trials, subjects named the pictures, but on the target trials they made an auditory lexical decision before naming the picture. The targets were presented at a short (73 ms), medium (373 ms), or long (673 ms) delay after the onset of the pictures. As in Schriefers et al., there were unrelated, semantically related, and phonologically related conditions. In addition, Levelt et al. tested a mediated condition where the target was a phonological neighbor of a semantic relative (e.g., picture = *sheep*; semantic relative = *goat*; target = *goal*). According to Levelt et al., interactive spreading activation accounts predict that a priming effect should be observed for both the mediated and directly phonologically related targets, whereas finding phonological activation only in the direct condition would be compatible with a modular account in which phonological activation is confined to a discrete stage and restricted to selected lemmas.

Levelt et al. consistently found inhibitory effects of semantic and phonological relatedness at the short stimulus onset asynchronies (SOAs). However, they found no mediated phonological effect. Also, consistent with Schriefers et al., they found evidence of phonological but not semantic activation at the long delay. But the results contrasted with those of Schriefers et al. in two respects. First, there was no point at which semantic but not phonological activation was observed. The obvious explanation for this is that the targets always lagged the pictures. There was evidently time for phonological activation to occur before the lexical decisions were made, even at the shortest SOA. Secondly, the late phonological effect was inhibitory rather than facilitatory.

This pattern of phonological inhibition in the absence of semantic priming late in the production cycle receives independent confirmation in some recent research of our own (O'Seaghdha & Dell, 1991a). In this research, rather than exploring the time-course of lexical access, we examined a condition in which single words were fully prepared. Our rationale was that this condition provides a clear benchmark for production priming effects. We presented pairs of words at upper and lower locations on a CRT for 1500 ms. Subjects were instructed to read these words. After a 1000-ms blank interval, an arrow appeared, pointing to the former location of one of the words (Figure 1). The arrow was the subject's cue to prepare to say this word, and not the other one which we call the alternate. After 1000 ms of preparation time, one of two possibilities occurred. On two-thirds of the trials an asterisk appeared, signalling the subject to utter the prepared word. On the remaining critical trials, a probe word appeared, and the subject named this target instead of producing the prepared word. The target was related to either the prepared word or the alternate, or it was unrelated to either word. In separate experiments, the relatedness manipulation involved semantic and phonological targets. Just as in the long SOA conditions of Levelt et al., we found inhibition of words phonologically related to prepared words, but no effect for semantically related targets (see Table 1(a)). There was no effect of relatedness to the alternate word for either phonological or semantic targets, indicating that the

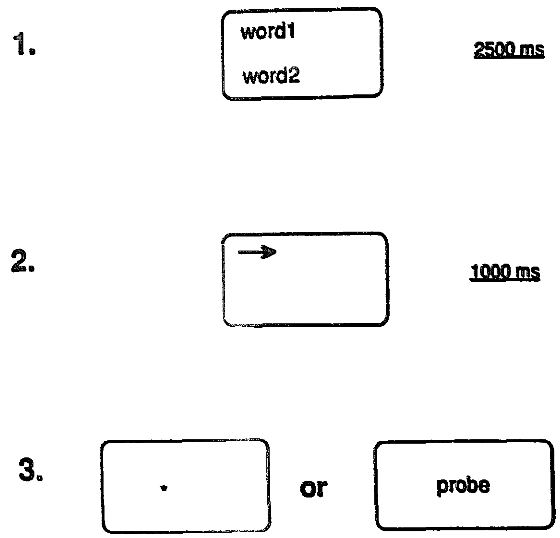


Figure 1. *The procedure in the single-word preparation experiment of O'Seaghdha and Dell (1991a).*

Table 1. *Naming latencies to word targets as a function of their relation to prepared utterances*

(a) Single-word preparation (choice procedure)

	Semantic target	Form-related target
Prepared	538	601
Alternate	543	582
Unrelated	548	583

(b) Sentence preparation (construction procedure)

	Semantic target		Form-related target	
	Related	Unrelated	Related	Unrelated
Passive sentence (critical word early)	672	680	728	706
Active sentence (critical word late)	683	681	702	721

(c) Sentence preparation (reiteration procedure)

	Semantic target		Form-related target	
	Related	Unrelated	Related	Unrelated
Passive sentence (critical word early)	580	607	627	618
Active sentence (critical word late)	584	599	615	627

phonological effect for prepared words was an effect of preparation, not merely of exposure to the word. Thus, our findings corroborate the results of Levelt et al., using a different procedure and a different response task.[1]

We provisionally interpret the phonological inhibition effect as competition between the discrepant phonological segments of the prepared word (the prime) and the presented word (the target) (O'Seaghdha et al., in press; Peterson, Dell, & Seaghdha, 1989). That is, when planning to produce the target, subjects are influenced by its similarity to the prime. Specifically, there is an increased tendency for segments from the prime to be inserted into the phonological plan of the target. In essence, we believe that the phonological inhibition effect is like the repeated phoneme effect in phonological speech errors (e.g., Dell, 1986). Any similarity between the production plans of activated words increases the chance that contrasting segments will move from one word to another. Thus, the contrasting segments of the prime tend to "slip" into the plan for producing the target. We assume that correction of this tendency incurs a cost in naming time or in any other response that depends on the phonological representation of the target (e.g., Bock, 1987). We also surmise that facilitation rather than inhibition was observed by Schriefers et al. because phonological competition did not arise in their procedure. This could be because no response is required to the words in the picture interference paradigm or because the words were not recognized soon enough to compete. (Similarly, phonological facilitation in production is found in the "implicit primes" task (Meyer, 1990, 1991) in which there is no phonological competition between contrasting segments.) We interpret the absence of a late semantic effect, in agreement with Levelt et al., as indicating a null or negligible level of semantic activation late in the process of producing a single-word utterance.

Because the application of priming techniques to the study of language production is such a recent development, the empirical picture on the discreteness question is still somewhat sketchy. Nonetheless, the framework of language production theory, in combination with the new empirical work, allows us to tentatively identify at least three phenomena to be explained. These are: early semantic activation without phonological activation (Schriefers et al.); the absence of mediated semantic–phonological priming in the presence of both direct semantic and direct phonological priming (Levelt et al.); and the presence of phonological priming in the absence of late semantic priming (all of the studies agree on this point). The first and last observations can be considered as two aspects of the time-course question, so we are left with two primary issues, both of which bear on whether the two steps of lexical access are discrete or continuous. These issues

[1]We used a naming task in the reported experiment, but we have obtained similar results with lexical decision (see O'Seaghdha & Dell, 1991a).

are the status of mediated semantic–phonological priming, and the time-course of semantic and phonological activation. Both Schriefers et al. and, more strongly, Levelt et al., favor a discrete, modular, two-step account of lexical access over an interactive spreading activation view, and they argue that the evidence supports the discrete account. However, we have recently argued (Dell & O'Seaghdha, 1991) that the evidence is compatible with a more interactive account, and that that account is to be preferred because of its ability to explain certain speech-error effects. We first outline the structure and motivation of the spreading activation framework, relying for the most part on the model of Dell (1986). Then we will consider how it addresses the mediation and time-course issues we have just identified.

Lexical activation in an interactive framework

In this section, we adapt the spreading activation model of Dell (1986, 1988, 1990; Dell & Reich, 1981) to address the discreteness question. Like discrete stage models, non-discrete spreading activation models distinguish between semantic–conceptual units, lemma or word units, and phonological units. As shown in Figure 2, the units are organized into a network in which the connections allow for a bidirectional spread of activation between units at adjacent levels. For example, an activated word unit will pass activation downward to phonological units and upward to semantic units. Activation levels are positive real numbers

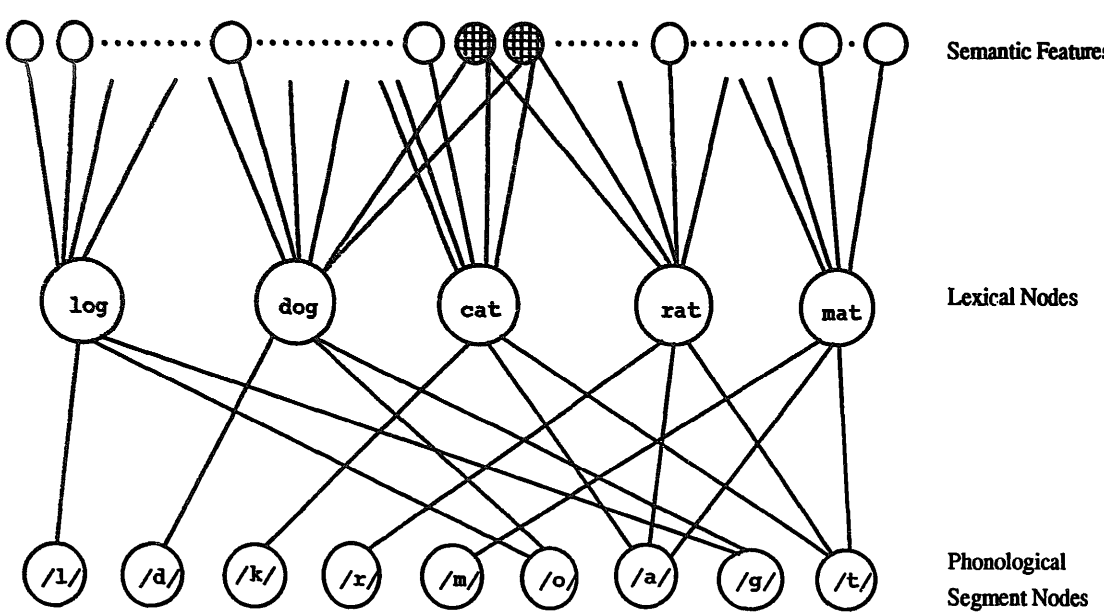


Figure 2. *Lexical network structure in the spreading activation production model. The figure illustrates the case where two features (highlighted) are shared by the three semantically related lexical nodes. The phonological labels are informal. (From Dell & O'Seaghdha, 1991; copyright 1991 by the American Psychological Association.)*

and are determined by external inputs and a linear activation updating function with a decay factor. As described in Dell and O'Seaghdha (1991), lexical access involves the following six steps:

(1) The semantic units of the concept-to-be-lexicalized receive external inputs.

(2) Activation spreads in an unconstrained fashion throughout the network, as determined by the activation updating function.

(3) The most highly activated word unit is selected. In the case of sentence production, selection entails the linkage of this unit to the developing syntactic frame for the sentence (see, for example, Bock, 1982, 1987; Stemberger, 1985), and is followed by post-selection inhibition, setting the unit's activation to zero (see MacKay, 1987; Shattuck-Hufnagel, 1979).

(4) When the word is ready for phonological encoding, it is given a triggering jolt of activation. For multi-word utterances, which require advance planning, the timing of this external signal is controlled by the syntactic frame slot that the unit is linked to. In the case of a single-word utterance, as in the studies we are currently considering, we assume that the jolt is supplied immediately upon selection.

(5) Activation continues to spread as before, but because of the extra activation of the selected word unit the appropriate phonological units become significantly activated.

(6) The most active phonological units are selected and linked to slots in a constructed phonological wordshape frame, a data structure analogous to a syntactic frame. (Recall that we proposed an account of phonological inhibition effects above in terms of competition. This competition could arise in the filling of the slots of such wordshape frames.)

Much of the motivation of this interactive model lies in its ability to account for a range of speech-error phenomena, particularly the effects of the familiarity of the error string and the similarity of the target and error utterances. Semantic, phonological, and mixed word substitution errors are most relevant here. In these errors, the fact that the substituting and replaced words are very often from the same grammatical class has been taken as evidence that these are lexical rather than segmental errors (see Fay & Cutler, 1977). Phonological word substitutions, or malapropisms, are errors in which a word is replaced by a phonologically related word. For example, if the semantic units for *cat* are active, the word *cat* becomes active, and this, in turn, activates /*k*/, /*ae*/, and /*t*/. These active phonological units then send activation to all words connected to them, for example *mat* in Figure 2. Thus, phonologically related words acquire some activation and one of them may be erroneously selected (step 3). On this view, a malapropism is the result of activation spreading between word and phonological units prior to lexical selection. Semantic word substitutions are explained similarly, except that the competing words are activated by shared semantic features. Thus, *dog* shares some features with *cat* and therefore may compete with it at the selection step. Finally, a mixed error is a word substitution exhibiting both a semantic and a phonological relation (e.g., *start*→ *stop*; *cat*→ *rat*). The important point about mixed errors is that they are much more likely than would be predicted from the independent contributions of phonological and semantic similarity (Dell & Reich, 1981; Harley, 1984; Martin, Weisberg, & Saffran, 1989). Therefore, mixed errors suggest an interactive influence of semantics and phonology in lexical selection.

We now examine the activation levels of words embodying the semantic, phonological, and mixed semantic–phonological relations we have just described, as well as the mediated semantic–phonological relation of Levelt et al., in an implementation of the spreading activation network depicted in Figure 2. The challenge to the spreading activation model is to account for the new empirical data without compromising the attributes that enable it to account for the word substitution errors.

Simulation of lexical activation levels

Consider how the activation of words exemplifying the relevant relations is simulated in the network depicted in Figure 2. With this model, we can compare the activation of an intended word, *cat*, a phonologically related word, *mat*, a semantically related word, *dog*, a semantically and phonologically related word, *rat*, and a word that is phonologically related to the semantic relative, *log*. We call *rat* the mixed word and *log* the mediated word.

By allowing activation to spread in the network we are simulating steps 1 and 2 of the spreading activation model. The simulation was implemented with the following rules:

(1) *Updating function*: $a(j,t) = a(j,t-1)(1-q) + Input\ (j,t)$

This is the standard linear activation function: $a(j,t)$ is the activation of unit j at time t, *Input* (j,t) is the input to j, and q is the decay rate.

(2) *Input function*: $Input\ (j,t) = \sum_i w(i,j)a(i,t-1)$

This is the standard weighted sum rule, where $w(i,j)$ is the weight from unit i to unit j, all the weights are equal to p, $0<p<1$, and the summation is over all units.

(3) All connections are bidirectional

We set $p = .1$ and $q = .4$, choosing these settings to keep the overall level of activation within reasonable bounds (Dell, 1986, 1988, 1990; Shrager, Hogg, & Huberman, 1987). By using a single connection weight, p, for top-down and bottom-up connections our model has the same degree of "interactiveness" as previous implementations that used interaction to account for the lexical bias effect (the tendency for slips to create words rather than non-words), the repeated phoneme effect (the tendency for sounds in similar environments to exchange), and other errors (Dell, 1986, 1988, 1990).

To enable us to simulate degrees of semantic relatedness, we arbitrarily assigned ten semantic "features" to each lexical concept. In separate simulations, the words semantically related to the intended word *cat* (*dog* and *rat*) shared one, two, or three features with it. Phonologically related words shared two out of three phonological segment nodes. Figure 3 shows activation of all of the word nodes as a function of time. In Figure 3(a), semantically related words share one feature, in Figure 3(b) they share two features, and in Figure 3(c) they share three features. After ten cycles, each figure shows that *cat* attains the highest activation,

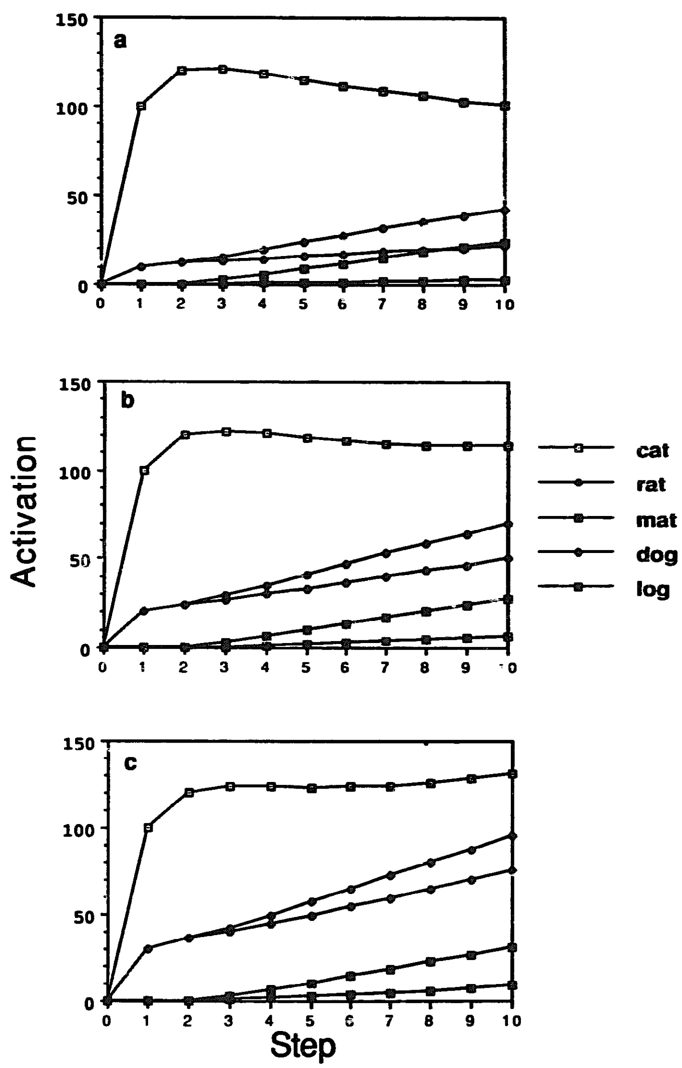


Figure 3. *Activation of word nodes as a function of time. Panels a, b, and c show the results when one, two, and three semantic features are shared by* cat, rat, *and* dog. *(From Dell & O'Seaghdha, 1991; copyright 1991 by the American Psychological Association.)*

rat has the next highest activation, and *log* attains only a small fraction of the activation of *rat*. The semantically and phonologically related words *dog* and *mat* are intermediate to *rat* and *log*, their relative activation levels depending on the number of shared semantic features.

It is easy to show that these activation levels translate into the required pattern of speech errors when a stochastic selection rule (e.g., McClelland & Rumelhart, 1981) is applied (see Dell & O'Seaghdha, 1991). For present purposes, it is sufficient to consider the activation levels. The important result is that there is approximately a tenfold difference in activation levels between the mixed condition (*rat*) and the mediated condition (*log*). This is because in the spreading activation model the mixed condition receives convergent, additive activation from semantic and phonological sources, whereas the mediated condition receives divergent activation in which the contributions of semantic and phonological relations are diluted. In the mixed case, *rat* receives activation from semantic and phonological nodes shared with *cat*. But in the mediated case, *log* receives only phonological activation from the mediating word *dog*, and this activation is scaled down by the relatively weak activation of the mediator. The amount of activation of the mediating condition can be estimated by the activations of the direct semantic (*dog*) and phonological (*mat*) conditions. If *dog* and *mat* are activated to, say, 20% of the level of the intended word *cat*, then *log*'s activation will be on the order of 4% of *cat* (.2 × .2) (see Dell & O'Seaghdha, 1991). Thus, to account for the absence of mediated priming, we are making the strong assumption that competing words are normally not nearly as activated as the target word. Whether this is true or not is difficult to tell since we cannot measure these activations directly. Nonetheless, our account works in the sense that it allows for speech error effects that we attribute to interaction such as mixed errors, but it does not demand that appreciable levels of mediated priming occur. We now consider in more detail the implications of the simulation for the mediated priming issue, and for the time-course of semantic and phonological activation.

Mediated priming

The first outcome to be explained is the absence of a mediated semantic–phonological priming effect in the Levelt et al. study. Recall that Levelt et al. suggested that the spreading activation model might lose its ability to account for the mixed error effect if the parameters were set in such a way that mediated priming was not observed. In our simulation, activation in the mixed condition was substantial, but in the mediated condition it was quite small. Nonetheless, our spreading activation model does suggest that priming in the mediated condition should be small rather than non-existent. What then is the true status of mediated semantic–phonological priming?

Apart from the Levelt et al. study, the issue of mediated priming has been addressed only in the receptive domain, and primarily for semantic mediation, for example, *lion* priming *stripes* through the mediation of *tiger* (Balota & Lorch, 1986; de Groot, 1983; McNamara & Altarriba, 1988; but see McNamara & Healy, 1988). We note that semantic–phonological mediation appears to involve a better defined manipulation than the semantic mediation studies. Although careful norming procedures were employed in the semantic mediation studies, it may be impossible to provide an entirely satisfactory discrimination between direct and mediated priming within the semantic domain. That is, though the items may have a very low probability of being mentioned as associates, they may nonetheless have some semantic relationship. For example, *sky – color* and *navy – tank* are among the mediated pairs in Balota and Lorch (1986) and McNamara and Altarriba (1988). In addition, several of the targets in these studies were antonyms of the mediating words or bore a contrastive relation to the mediators (e.g., *black – white*; *summer – winter*) and therefore shared many features with them. On our account of spreading activation, for any items that are to some extent directly activated there is convergent activation from the prime and the mediator. Therefore, there could be substantial priming in some cases. These considerations suggest that the mediated priming effect should be smaller in the case of semantic–phonological mediation than in the case of semantic–semantic mediation.

Another factor that may account for Levelt et al.'s null mediated priming effect is their choice of lexical decision as the response task. Balota and Lorch (1986) observed mediated semantic priming in naming but not in lexical decision (see also de Groot, 1983). McNamara and Altarriba (1988) did observe mediated semantic priming in lexical decision, but only under conditions that excluded directly related pairs or that made it difficult to notice whether the pairs were related. This suggests that mediated priming effects may be obscured by the relatedness checking that often characterizes lexical decision (Balota & Lorch, 1986; McNamara & Altarriba, 1988).

Thus, we conclude that mediated semantic–phonological effects should be small, but we leave the determination of just how small to future research. The spreading activation model suggests that there may be a slight effect, whereas the modular two-step account states that there should be none.

Time-course of semantic and phonological activation

In accordance with the modular view of lexical access, Schriefers et al. (1990) observed semantic activation early in the process of picture naming when there was no evidence of a phonological effect. Levelt et al. (1991) also argue that their findings are compatible with an early stage of exclusively semantic activation. However, we note that their data do not provide direct evidence of this. Rather, they observed both semantic and phonological effects at the shortest picture–

word asynchrony (73 ms). The claim that there is an early stage of exclusively semantic activation then depends on the reasonable assumption that this stage has been passed at the time of lexical decision even in the short SOA condition. At the other end of the lexical production process, Schriefers et al. (1990), Levelt et al. (1991) and O'Seaghdha and Dell (1991a, 1991b) observed phonological activation in the absence of semantic activation late in the process of producing one-word utterances.

Given these data and our discussion of mediated priming, our general answer to the discreteness question is that the production system is globally modular, but locally interactive (see Dell & O'Seaghdha, 1991). To explain what we mean here, we turn again to the spreading activation model.

Role of external signals. In a full-scale model of language production (see Dell, 1986, and our summary above), the scheduling of semantic and phonological activation in the lexical network is strongly influenced by external inputs from modular linguistic rule systems. These signals add greatly to the level of activation of the units receiving them, and thus strongly influence the levels of activation at the different levels of the lexical network. In essence, these signals impose the rule-governed structure of language at each level by determining when a selected unit is realized at a lower level.

If our limited model in Figure 2 were expanded to include external signals, an external signal would come from the conceptual system, as well as from the syntax (which sends a signal to each selected word unit), the phonology (which sends a signal to each selected phonological segment), and the corresponding structural frames at lower levels (e.g., MacKay's, 1987, sequence nodes at the feature and motoric levels).

Consider the following illustration from Dell and O'Seaghdha (1991). Figure 4 shows a simplified network consisting of a single column of semantic, word, phonological, and phonetic/articulatory nodes. Assume that $p = .1$, that $q = .4$, and that a standard external signal of 1.0 is given to the semantic unit. After eight time steps, the lexical node is selected and set to zero, and receives a signal of 1.0 from the syntax. After eight more steps, the phonological node is selected in the same way, a standard signal from the phonology is given to it, and so on. Figure 5 shows the activation levels of the nodes over time. The important feature of the figure is that there is a distinct time-course of semantic and form-related activation. Viewed from a distance one sees a modular system, in which the initial stage involves no phonological activation and where the final stages have next to no semantic activation. Thus, the time-course is globally modular. The sequence of external signals is purely serial and top-down and, with these parameters, the external signals largely determine the time-course of activation. However, the top-down and bottom-up spreading activation process within the lexicon does contribute some local interaction. When most of the activation is at level N, there is also some at levels $N+1$ and $N-1$. It is this exchange of activation between

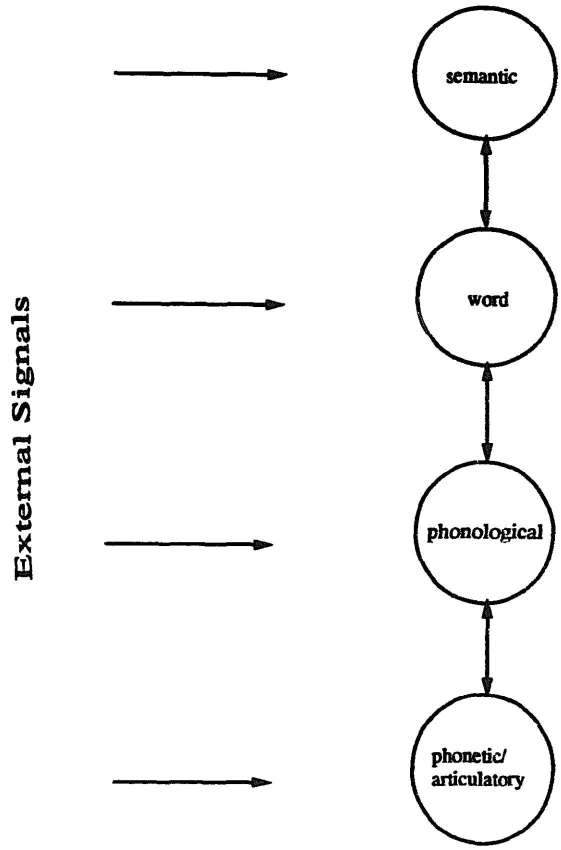


Figure 4. *A simplified network in which external signals are received in sequence by nodes at four representational levels. (From Dell & O'Seaghdha, 1991; copyright 1991 by the American Psychological Association.)*

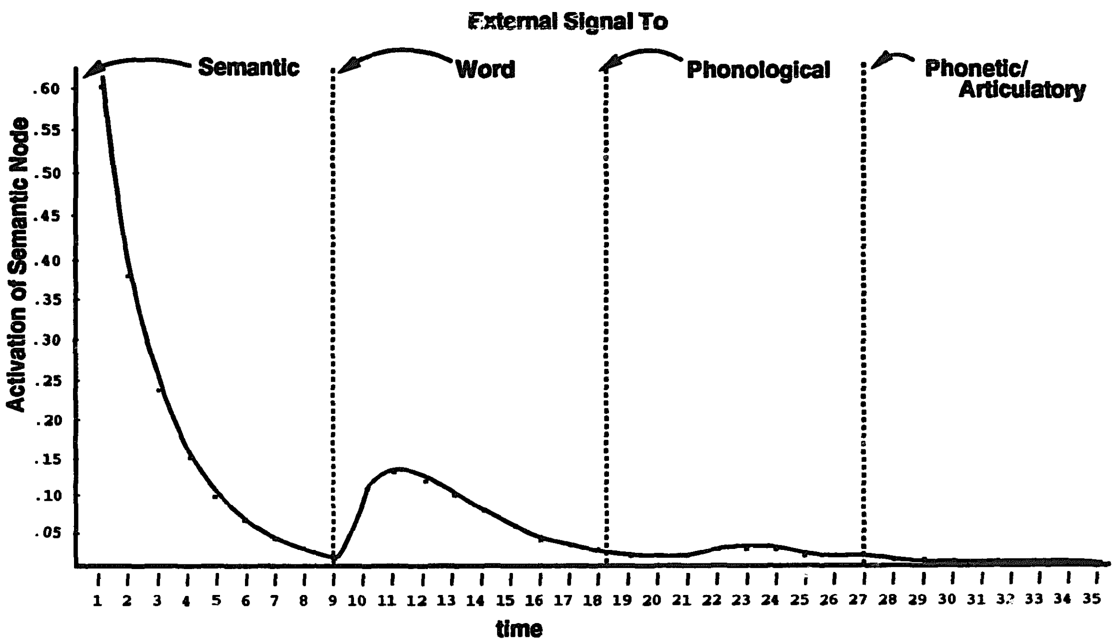
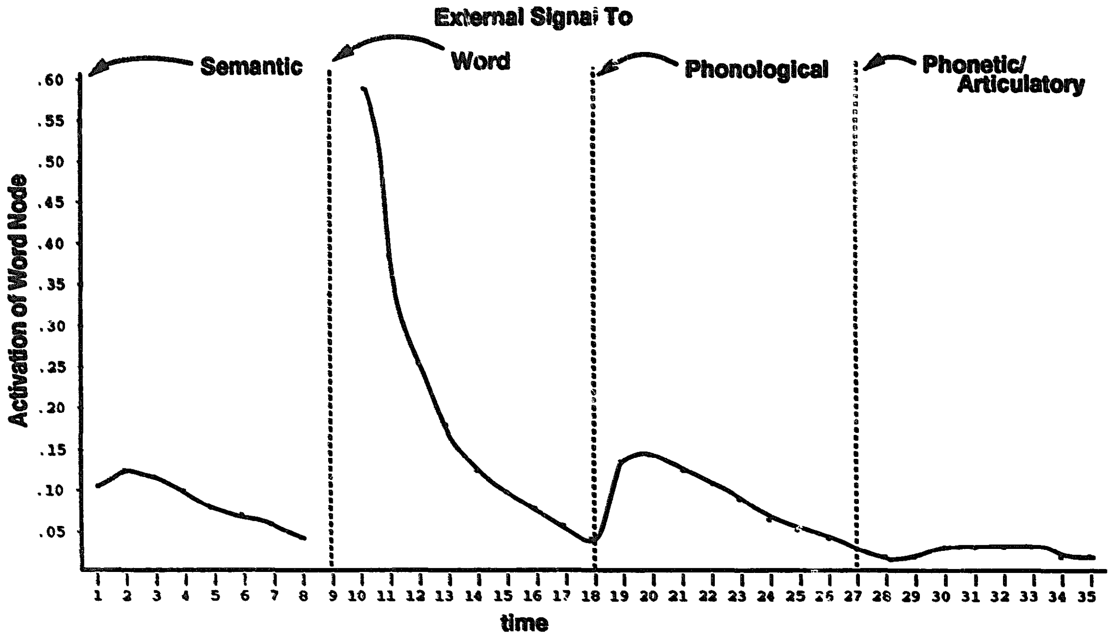
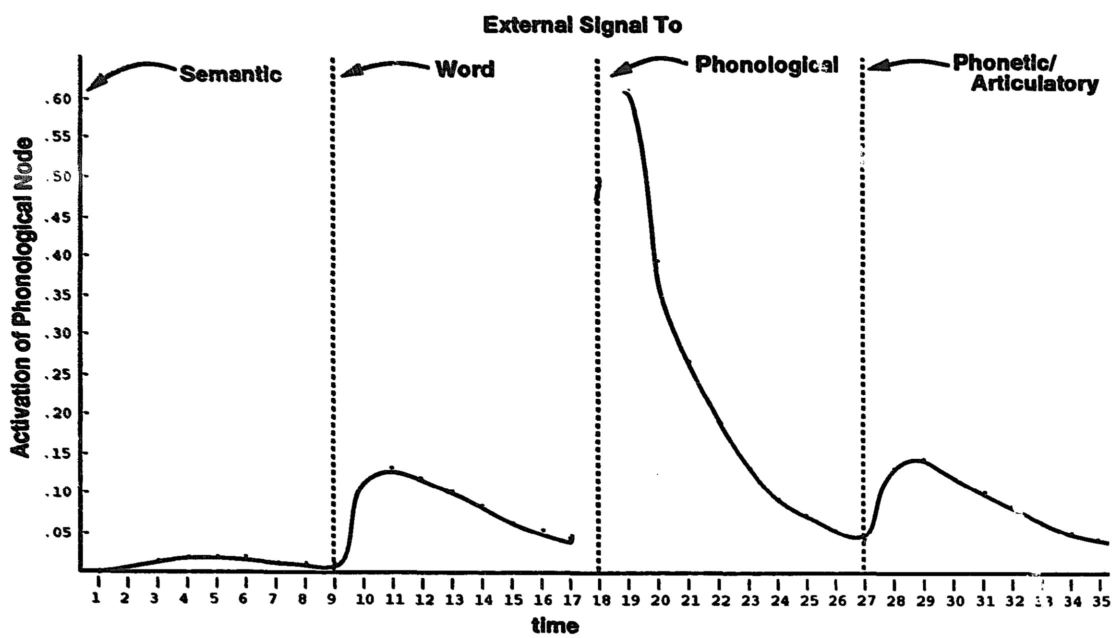


Figure 5. *The activation of the semantic, word, phonological, and phonetic–articulatory nodes of Figure 4 as a function of time. At time steps 0, 9, 18, and 27, external signals of 1.0 are sent to the semantic, word, phonological, and phonetic–articulatory nodes, respectively. (From Dell & O'Seaghdha, 1991; copyright 1991 by the American Psychological Association.)*

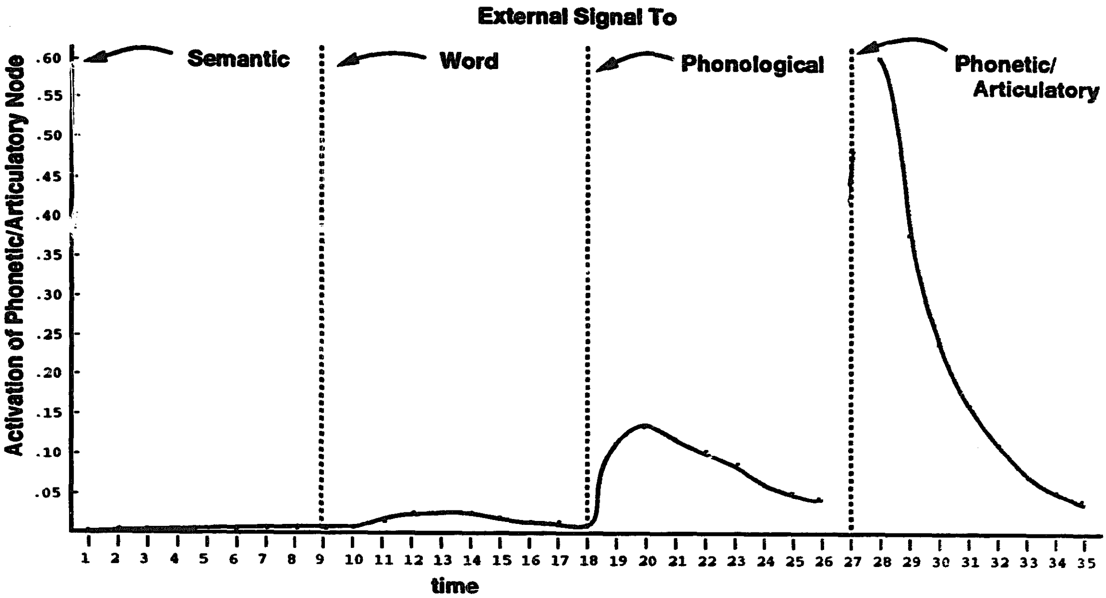


(b)



(c)

Figure 5 continued.



(d)

Figure 5 continued.

nodes at adjacent levels that gives the spreading activation model the ability to account for interactive error effects such as mixed errors.

We conclude that studies of the time-course of the access of single words support the claim that the system is globally modular. This is because linguistic rule systems supply external activation to discrete levels of the lexical network (Dell, 1986; Dell & Reich, 1981). However, this does not mean that interaction within the lexical network can be discounted. Rather, speech errors suggest that interaction in the lexical system allows for the mingling of information from different levels. In the spreading activation model, this mingling is most evident when activation sources converge.

The advance planning question

Thus far, we have considered the time-course of the production of single words, specifically the question of the discreteness of lemma and phonological form retrieval. Obviously, things become more complex when these issues are addressed in the context of sentence production. We begin by reviewing the rough consensus regarding the components of sentence production that has emerged primarily from the study of speech errors and other dysfluencies in natural and experimental contexts.

Theorists have identified three major stages of production planning: a conceptual, a linguistic, and an articulatory stage (see Levelt, 1989). In the conceptual stage, a "message" or semantic representation of the utterance is formed. For our purposes, this may be viewed as an organized set of propositions standing in relation to a speech act (e.g., inform, request). The goal of the second stage, linguistic encoding, is to turn the message into the form of a sentence or sentences. And the goal of the third, articulatory stage is to produce speech. Our primary focus will be the linguistic encoding stage. Nearly all production theorists agree that linguistic encoding involves the construction of more than one distinct linguistic representation of the utterance (e.g., Bock, 1982; Dell, 1986; Garrett, 1975; Kempen, 1978; Levelt, 1989; MacKay, 1982; Shattuck-Hufnagel, 1979; Stemberger, 1985). In keeping with our earlier distinction between lemma access and phonological access, these theorists agree that there are distinct levels of utterance representation whose basic elements are lemmas and sublexical phonological units. The first level, which is constituted of lemmas, encodes the syntactic structure of the sentence. We refer to it as the syntactic level, though we recognize that it may also encode other kinds of linguistic information and, in fact, may consist of more than one representation. The second level is constituted of phonological segments, and it encodes the phonological forms of lexical items.

Thus, the distinction between lemmas and phonological forms that we have been working with is also critical to distinguishing the syntactic and phonological representations of sentences. With regard to advance planning, the focus of interest becomes the time-course of the construction of these representations. We introduced this topic earlier in the context of the lemma buffering hypothesis which states that, in sentence production, multiple lemmas must be held in readiness at the syntactic level pending the later activation of corresponding units at the phonological level. The best evidence on the nature of lemma buffering comes from the speech errors we have discussed, and from patterns of pausing and hesitation in speech (e.g., Butterworth, 1980; Cooper & Paccia-Cooper, 1980; Ford, 1982; Garrett, 1980; Holmes, 1988). These studies are in agreement that the extent of advance planning at the syntactic level exceeds the extent of planning at the phonological level.

In the case of speech errors, syntactic-level speech errors (e.g., word exchanges such as "*The test will be about discussing the class*") span greater distances than phonological-level errors (e.g., sound exchanges such as "*thollow hud*"). Because this suggests that the selection of lemmas can lead the selection of their phonological forms, it indicates some kind of buffering of lemmas. Speech error data also show that most word exchanges and over 90% of sound exchanges involve units from the same clause (Garrett, 1975). Likewise, hesitations in spontaneous speech often occur at clause boundaries (e.g., Holmes, 1988), and clause boundaries block the application of some phonological rules (Cooper & Paccia-Cooper, 1980). Therefore, a good working hypothesis is that the syntactic representation is constructed in clausal units (Butterworth, 1980; Garrett, 1980). That is, lemmas within a clause may be simultaneously processed, but those in separate clauses typically are not.

A specific model in which the clausal structure of the utterance determines when lemmas are retrieved has recently been proposed by Levelt (1989). The model distinguishes between the initial activation of lemmas, which occurs as the underlying propositions of the utterance are scanned, and the insertion of lemmas into a syntactic tree. The relevant unit of the initial scanning is the "deep" clause or proposition, and that of the insertion is the "surface" clause.

This model finds support in studies of hesitations in spontaneous and read speech. In spontaneous speech, a hesitation is likely after the matrix verb (*expect* in the examples) when it is followed by either a finite (e.g., *I expect the cat will chase the mouse*) or a non-finite (e.g., *I expect the cat to chase the mouse*) clause (Ford, 1982; Holmes, 1988; see Ford & Holmes, 1978). This result can be seen as reflecting the "deep" clausal organization corresponding to the initial scan component of Levelt's proposal. In read speech, finite clause boundaries attract more pauses than non-finite ones (Holmes, 1988). This sensitivity to surface clausal organization in read speech is exactly what would be expected from Levelt's account on the assumption that reading aloud involves the insertion of lemmas into a syntactic tree, but not the creation and scanning of a propositional representation.

If the clause is the domain of advance planning at the syntactic level, what is the corresponding domain at the phonological level? The speech-error evidence that word exchanges span longer distances than sound exchanges suggests that phonological advance planning is less extensive than the advance planning of lemmas, but it does not identify a domain over which phonological planning operates. At least three hypotheses on the extent of phonological planning warrant consideration:

(1) *The word-by-word hypothesis*. Only the word about to be uttered and the following word are prepared, regardless of the structure of the sentence. This view has the advantage of simplicity and it may be all that is needed in order to accommodate phonological and phonetic rules (Levelt, 1989). That is, the proper phonetic form of a word can be known as long as the phonological forms of only the adjacent words are known.

(2) *The syntactic-structure hypothesis*. Words are phonologically planned in accordance with syntactic units. Given that phonological advance planning should be less extensive than syntactic, the most common proposal has been that phonological forms are retrieved in subclausal chunks corresponding to major syntactic phrases (e.g., Dell, 1986; Garrett, 1975; Lapointe, 1985).

(3) *The prosodic-structure hypothesis*. Several researchers have recently suggested that phonological advance planning may be related to the prosodic structure of the utterance rather than to its syntactic structure (Bock, 1982;

Ferreira, 1991; Gee & Grosjean, 1983; Garrett, 1980; Levelt, 1989; Selkirk, 1984). In prosodic structures, phonological words are concatenated to form phonological phrases which are, prototypically, a content word and any preceding function words. One or more phonological phrases may then constitute an intonational phrase, a level of analysis over which intonational contours are computed. Some studies of pausing have found that the prosodic hierarchy does better than syntactic structure at predicting pauses (Ferreira & Clifton, 1987; Gee & Grosjean, 1983), suggesting that prosodic grouping may also play a role at the syntactic level (see above). For the most part, however, prosodic units such as phonological phrases correspond to syntactic phrases (e.g., subject NPs), and it is therefore very difficult to distinguish between the syntactic and prosodic hypotheses.

At this point, there is simply not enough evidence to make a strong argument for any of the hypotheses concerning either planning of lemmas or planning at the phonological level. What is clearly needed is some way to experimentally assess advance planning of both lemmas and phonological forms. In earlier experimental work on planning in production (e.g., Kempen & Huijbers, 1983; Levelt & Maassen, 1981), researchers measured times to generate utterances while manipulating variables that would likely affect the difficulty of utterance planning at the different levels of processing. This research has helped to make the case for the distinction between concepts, lemmas, and phonological forms. We believe that the production priming techniques used by Schriefers et al. (1990), Levelt et al. (1991), and O'Seaghdha and Dell (1991a) may provide an additional experimental tool for studying the advance planning question, one that has the advantage of providing relatively direct measures of access processes. In the following section, we outline how this could be accomplished, and we present the results of two experiments to illustrate our suggestions.

Production priming and the advance planning question

The essentials of the production priming methodology used by Levelt et al. (1991) and O'Seaghdha and Dell (1991a) can be summarized as follows:

(1) The subject view a display whose purpose is to induce the preparation of an utterance.

(2) The subject prepares the utterance.

(3a) On a majority of the trials, the subject simply produces the prepared utterance and the trial ends.

(3b) On critical trials, a target word is displayed. The subject responds to the target and may or may not be required to produce the prepared utterance before the trial ends. The latency and accuracy of responses to targets are the dependent measures of interest.

Thus, production plans serve as primes, and the extent to which the primes influence responses to related targets assesses the extent and nature of the plans. Let us consider some of the experimental options that are available within this general scheme.

Inducing the preparation of utterances

At least four techniques are available to elicit the preparation of more or less pre-specified utterances:

(1) *Reiteration*. The most obvious procedure is to supply the subject with the content of the utterance, under instruction to produce it on a given cue (e.g., Balota, Boland, & Shields, 1989; Sternberg, Monsell, Knoll, & Wright, 1978). This procedure has the advantage that the utterance to be prepared can be completely pre-specified. However, there are two disadvantages. First, because subjects are merely repeating prescribed materials, we cannot be sure that production processes, particularly higher-level processes, are sufficiently engaged.[2] The second disadvantage is that the eliciting display (e.g., a visual display of a phrase to be repeated) may cause priming that cannot easily be separated from the effects of productive processes. The next procedure addresses this concern.

(2) *Choice procedure*. Here, subjects are given not one but two potential utterances. Then they are cued to prepare one of the two. Because two potential utterances are presented, but only one is prepared, the effect of the eliciting display can be factored out. This was the procedure we used in the experiments mentioned above (O'Seaghdha & Dell, 1991a), and it is related to the response priming procedure of Meyer and Gordon (1985; Gordon & Meyer, 1987).

(3) *Construction*. Many variations are possible under this heading, but their common theme is that subjects are given a set of ingredients together with instructions on how to combine them and are required to produce utterances in keeping with the instructions. For example, in one of the experiments that we report below subjects prepared sentences such as "*The boxer removed the coat*" from a quasi-propositional representation, REMOVE (BOXER, COAT).

(4) *Pictorial displays*. Many production researchers prefer to use pictures as eliciting displays (e.g., Bock, 1986; Levelt et al., 1991; Schriefers et al., 1990). By using carefully selected and normed pictures, it is possible to obtain reasonably consistent descriptions from subjects. The sequence from picture recognition, through sentence formulation and lexical selection, to the phonological specification of an utterance, conforms better to the process of natural language production than the other methods. However, working with pictures necessarily intro-

[2]But see Potter and Lombardi (1990) for recent evidence that reiteration of sentences may entail regeneration of utterances from conceptual representations.

duces variability in the utterances and thus limits the practical complexity of the desired utterances to single words or simple phrases or sentences.

Relations between targets and utterances

One of the greatest advantages of these priming techniques for studying lemma and phonological form retrieval is that one can index different levels of representation by using different prime–target relations. Both Levelt et al. (1991) and Schriefers et al. (1990) were able to track the time-course of lemma and phonological access by comparing phonological and semantic prime–target relations. We also used these relations in the experiments we report below. However, a new wrinkle in our research is that we distinguish between phonological facilitation and phonological inhibition and argue that these may reflect different aspects of lemma and phonological access.

Choice of task

Two standard tasks, word naming and lexical decision, are widely employed in the priming literature. Naming is the more straightforward of the two tasks; it is both simple and natural. In addition, it involves a production component, and thus to some extent taps into the systems whose representations we wish to investigate. A potential limitation of word naming is that performance may be so fast and skilled that it is largely immune to interference and insensitive to facilitation (Forster, 1981). Lexical decision, in contrast, is more artificial, but has the advantage that priming effects are often larger than in the naming task. For example, Levelt et al.'s (1991) use of auditory lexical decision to track lexical access in production resulted in effects as large as 100 ms. However, there is a potential drawback of using lexical decision in production priming experiments. In contrast to the receptive priming situation where subjects typically merely read the prime and then respond to the target, in a production priming experiment subjects prepare an utterance, but on some fraction of trials are instead required to respond to a target. If the specified response to this target is lexical decision rather than naming, subjects are required to switch tasks as well as responses when the target is presented. This complication would be expected to slow latencies and thus make the task a less direct index of the state of preparation at the moment of target presentation. Therefore we tend to favor the use of naming rather than lexical decision, provided it proves sufficiently sensitive.

Experiments on sentence production

We have recently completed two experiments investigating the advance planning question using production priming (O'Seaghdha & Dell, 1991b). Both experiments employed naming as the response task. The first involved a construction procedure. On each trial subjects viewed a visually displayed propositional representation of a potential utterance. On half the trials, propositions such as *REMOVE* (*BOXER*, *COAT*) were shown, and subjects immediately began to prepare simple past tense declarative sentences, in this case "*The boxer removed the coat*". On the other half of the trials the propositional display contained the word *by*, for example, *REMOVE* (*BY BOXER*, *COAT*). On these trials, subjects were instructed to prepare a passive sentence, "*The coat was removed by the boxer*". Subjects pressed a response button as soon as they had prepared each utterance. Half a second after the button press, the subject either saw an asterisk on two-thirds of the trials, or a target word on the other one-third of trials. The asterisk was simply a signal for the subject to produce the prepared sentence. If a target appeared, the subject named it as quickly as possible. After the subject's naming response, an asterisk appeared and the subject produced the prepared sentence. The target words were designed to tap into the representation of the logical direct object of the prepared sentence (e.g., *COAT*). In the passive condition, the critical word was early in the first phrase of the sentence. In the active condition, it was the last word of the sentence. The target words were either phonologically related to the critical word (*COAL*), semantically related (*SHIRT*), or unrelated. The unrelated target words served as related targets for other sentences tested with other subjects, following standard counterbalancing procedures.

The phonological priming effects (unrelated RT – related RT) revealed a compelling dependence in the planning process (see Table 1(b)). When the critical word was early in the sentence, responses to phonologically related targets were significantly inhibited (−22 ms). This result extends the inhibition found in the single-word case (O'Seaghdha & Dell, 1991a), described earlier, to sentences. It is also important in that the critical word in this case is not, strictly speaking, the first word in the sentence. Rather, each sentence began with the determiner *the*. In contrast with this inhibitory outcome, when the critical word was late in the sentence we found a significant facilitatory effect for phonologically related primes (+19 ms). So, the phonological relatedness effect is turned around when the critical word is not imminent. We take the difference in phonological priming to reflect a difference in the nature of the sound-based plan for early and late words in an utterance. The harder thing to explain is the nature of this difference. We offer the following tentative interpretation, based on the notion of phonological competition described earlier.

We view the inhibitory effect as indicative of a state in which the access of the phonological form of the prime is complete or nearly complete. Similarity-based competition occurs only when both the identical and the contrasting segments of the prime are present. The identical segments must be there so that the target contacts the representation of the prime. The contrasting segments of the prime must be there to compete with the segments of the target. Thus we argue that, in the passive condition, the phonological planning of the second word in the sentence, *COAT*, was quite advanced.

The facilitatory effect obtained in the active condition, in which *COAT* is the last word in the sentence plan, reflects a lesser degree of planning of the word. In this case, the segments of *COAT* that would contrast with *COAL* are not present in sufficient strength to generate competition. In the absence of this competition, the opportunity arises for facilitation due to similarity to come into play. This might occur through preliminary activation of the initial segments of *COAT* and/or through the mediation of a shared wordshape frame (see Dell, 1986; Stemberger, 1990). We are tempted to conclude that the facilitatory effect indicates a stage in which only lemma access of *COAT* has been effected, whereas the inhibitory effect indexes full phonological access. In fact, this is exactly the case in a model of form-related priming that we have developed to account for the effects of frequency, masking, and homophony in the receptive domain (O'Seaghdha et al., in press; Peterson et al., 1989). However, pending development of an explicit production-oriented priming model, a more conservative conclusion is simply that inhibition indicates a great deal of progress toward a full specification of the critical word's form, whereas facilitation indicates a much lesser degree of preparation.

The results for semantically related targets in the sentence construction experiment were less informative. The effects for the early and late conditions were 8 and −2 ms (see Table 1(b)) and were not significant. Thus, we were not able to contrast semantic and phonological aspects of advance planning in this experiment. We suggested earlier that construction should, in principle, engage production processes more fully than reiteration. However, in this case, the demands of the construction task may have prevented the engagement of semantic processes. Subjects may have been fully occupied by the need to rearrange the words according to the relevant syntactic formulae. A second experiment in which we employed the reiteration procedure instead of construction suggests that this may indeed have been the case.

In this experiment, subjects simply saw the sentences in either the active or passive versions for 1500 ms, and after a blank interval of 1000 ms were presented with either the signal to repeat the sentence or a target word. The results for phonologically related targets mirrored those of the previous experiment – inhibition in the early, passive condition, and facilitation in the late, active condition. But here we found a significant semantic effect as well, 27 and 15 ms for the early and late cases, respectively (see Table 1(c)). Most importantly, the general time-course of the phonological priming effects differed from that of semantic effects as shown by a significant triple interaction of type of relation, relatedness, and sentence structure (active or passive). It appears that position has much less influence on the amount and direction of semantic priming than it did with phonological priming.

This is exactly the result one would expect from the claim that planning at the lemma level exceeds that at the phonological level. The significant semantic and phonological facilitation in the active condition, where the critical word was late, can be taken as evidence of lemma retrieval. We cannot rule out the possibility that there is some phonological activation in this condition, but we can say that phonological activation in the early position is much stronger. Therefore, the kind of phonological access associated with inhibition lags behind lemma retrieval, giving evidence for some kind of lemma buffering.

Earlier, we introduced three contrasting hypotheses of advance planning at the phonological level: the word-by-word, syntactic structure, and prosodic structure hypotheses. However, our experiments do not fully arbitrate between these hypotheses. All three can accommodate a finding that coat in "*The coat*..." is phonologically ready prior to the utterance of *the*. Similarly, all three can deal with the absence of phonological inhibition for a word at the end of a single-clause sentence. The results do place some constraints on the syntactic and prosodic hypotheses, though. They suggest that the advance planning indexed by inhibition does not include a whole clause or an entire intonational phrase. (Subjects typically spoke the sentences in one intonational phrase). Whether the inhibition effect is present only on the next word or on words in the current phonological or syntactic phrase remains to be seen. We are currently studying this question by examining the inhibition effect with a choice procedure. For example, phrases such as "*COAT*", "*The COAT*", "*Another COAT*", "*In the COAT*", "*Around the COAT*", "*The big COAT*" and "*The very warm COAT*" can be compared as production primes for *COAL*, in order to examine the effects of additional words with differing prosodic and syntactic characteristics on advance planning within phrases.

Conclusions

Two questions have guided our inquiry into the time-course of lexical access: the question of the discreteness of the semantic–syntactic and phonological aspects of access, and the question of the extent of advance planning of these aspects. Our conclusions are, for the most part, in agreement with the standard view of production (e.g., Garrett, 1975; Levelt, 1989) in which the production system distinguishes between form-related and meaning-related processes. The reach of advance planning appears to be different for meaning and form, and meaning and form also appear to be separable over the time-course of the retrieval of individual words. Though this evidence tends to favor the idea of discrete stages in production, we believe that a degree of local interaction in the course of lemma and phonological access is necessary to account for mixed semantic–phonological speech errors. These effects can be accounted for entirely by assuming that the phonological and semantic–syntactic representations of words are connected in a lexical network. That is, the interaction is a product of lexical retrieval processes, not of the way that syntactic and phonological rule systems are represented and used.

The empirical focus of our paper has been on a still rather small body of recent research that applies priming techniques to the study of production. A principal advantage of this method is that it has the potential of providing relatively direct measures of activation at more than one level of representation. This potential was exploited by Levelt et al. (1991) and Schriefers et al. (1990) to reveal aspects of the time-course of semantic and phonological activation in the retrieval of single words. Likewise, our own initial studies of sentence production enabled us to discriminate between phonological and semantic levels of advance planning. Thus, the feasibility of using priming techniques to study production appears to be established. Given the level of agreement within the field on the overall architecture of the production system, we expect to see considerable advances in this decade in the detailed exploration of the subtler aspects of the control and coordination of language production.

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