

Speaking words: Contributions of cognitive neuropsychological research

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We review the significant cognitive neuropsychological contributions to our understanding of spoken word production that were made during the period of 1984 to 2004—since the founding of the journal *Cognitive Neuropsychology*. We then go on to identify and discuss a set of outstanding questions and challenges that face future cognitive neuropsychological researchers in this domain. We conclude that the last 20 years have been a testament to the vitality and productivity of this approach in the domain of spoken word production and that it is essential that we continue to strive for the broader integration of cognitive neuropsychological evidence into cognitive science, psychology, linguistics, and neuroscience.

INTRODUCTION

The founding of *Cognitive Neuropsychology* in 1984 marked the recognition and “institutionalisation” of a set of ideas that had been crystallising for a number of years. These ideas formed the basis of the cognitive neuropsychological approach and, thus, have largely defined the journal over the past 20 years (Caramazza, 1984, 1986; Ellis, 1985, 1987; Marin, Saffran, & Schwartz, 1976; Marshall, 1986; Saffran, 1982; Schwartz, 1984; Shallice, 1979). Chief among them was an understanding of the fundamental limitations of syndromes or clinical categories as the vehicles for characterising patterns of impairment. This was complemented by the realisation that the appropriate and productive unit of analysis was the performance of the individual neurologically

injured individual. Critical also was the more explicit formulation of the relationship between neuropsychology and cognitive psychology (Caramazza, 1986). The increasing application of theories of normal psychological processing to the analysis of deficits allowed neuropsychological evidence to provide significant constraints on theory development within cognitive psychology. This integration yielded the characterisation of cognitive neuropsychology as a branch of cognitive psychology.

These core ideas shaped the practice of neuropsychological research and the positive fruits of that research served, in turn, to confer greater legitimacy to and confirm these notions. One domain in which these ideas have been fruitfully applied is spoken word production. In this paper, we review the most significant cognitive

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neuropsychological findings in this domain from the period of 1984 to 2004. We then go on to discuss the research questions and challenges that we anticipate will be of interest in the next 20 years. We note that this review will be concerned solely with spoken naming of single words, and that we will exclude the related domains of sentence production and oral reading.

Spoken word production circa 1984

Ellis' (1985) review of the cognitive neuropsychological approach to spoken word production serves as an excellent snapshot of the state of cognitive neuropsychological research in spoken word production circa 1984. We will use this review as a starting point for identifying those areas in which significant progress has been made since 1984 in the cognitive neuropsychology of spoken word production.

As a backdrop to his review, Ellis used the framework depicted in Figure 1. This framework includes three major representational components: the conceptual semantic system, the speech output lexicon, and the phoneme level. This framework represents the general claim that in producing a spoken word we translate from a concept to a set

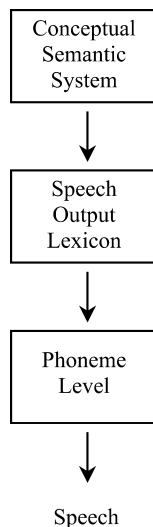


Figure 1. Ellis (1985)'s framework for speech production.

of phonemes through the mediation of lexical forms. Interestingly, this general two-stage framework still underlies most current work in spoken word production. The first stage involves the selection of a lexical item to express the concept a person has in mind, and the second stage specifies the phonemes that correspond to the selected item. The objective of research on spoken word production has been to develop an increasingly more detailed understanding of the representations and processes referred to in Figure 1. We will start our review by identifying the principal issues discussed by Ellis. We have decided to group them into the following three categories: *basic architectural distinctions*, *the internal organisation of the speech lexicon*, and *activation dynamics* (see Table 1).

Questions regarding *basic architectural distinctions* concern the fundamental representational and processing distinctions that are encoded in the functional architecture. First, there is the question of whether a single store of lexical knowledge is used for word comprehension and production or if, instead, there are dual lexicons. A second question is whether the system distinguishes between representations of word meanings (lexical semantic representations) and semantic knowledge of the world, including the representation of meanings for which there may be no words (Allport, 1983; Saffran, 1982). A third question is if word meanings and word forms are represented independently, or if, instead, they are aspects of a single lexical representation. And, finally, a fourth issue concerns the content and organisation of the phonological representations and processes themselves, with particular emphasis on a possible distinction between representations/processes that are phonemic (central, abstract) versus phonetic (peripheral).

Ellis reviews two major topics in the category of *the organisation of the speech output lexicon*. First, there is the issue of whether the organisation of the speech lexicon (the long-term memory store of the sounds of familiar words) respects distinctions among grammatical categories (i.e., nouns, verbs, function words). Second, there is the

Table 1. *Open theoretical issues, circa 1984; progress on these and related issues, 1984–2004*

Major issues identified in Ellis (1985)

Status 2004

<p>Basic architectural organisation: Are spoken comprehension and production served by a single lexicon? Are world knowledge and lexical semantics distinct? Are word meanings and word forms represented independently? How are phonemic and phonetic levels distinguished?</p>	<p>Basic architectural organisation: Open question Open question <i>The independent representation of word meaning and form</i> Open question <i>The independent representation of word form and word syntax</i></p>
<p>Representation and processing in the speech output lexicon: Does the speech lexicon respect grammatical category distinctions? Are morphologically complex words represented in a decomposed manner?</p>	<p>Representation and processing in the speech output lexicon: <i>Grammatical category distinctions at the level of the phonological output lexicon</i> <i>Morphologically decomposed word forms</i> <i>Lexical category distinctions at the level of the phonological output lexicon</i></p>
<p>Activation dynamics: What is the role of interactive activation in spoken word production? Specifically: <ul style="list-style-type: none"> • cascading activation • feedback • competitive inhibition </p>	<p>Activation dynamics: <i>Cascading activation from semantic-lexical-phoneme levels</i> <i>Feedback from phoneme to lexical levels</i> Open question</p>

question of whether morphologically complex words are represented in a unitary (whole word) manner, or in a morphologically decomposed manner.

With regard to *activation dynamics*, Ellis (1985) discusses the possibility that various aspects of impaired word production might be understood if we make certain assumptions about the temporal characteristics of activation and information flow. In particular, in his account of form-based lexical errors and phonemic cueing, Ellis includes the notion of partial or weak activation (in contrast to all-or-none thresholded activation). He also entertains the possibility of cascading activation and feedback from the phoneme level to the speech output lexicon, as well as a mechanism of competitive inhibition among lexical representations.

While it is certainly the case that very significant cognitive neuropsychological work was carried out on all of these questions prior to 1984, the last 20 years have provided considerable advances and, in many cases, consensus regarding some of the earlier findings. Furthermore, although there are probably no findings that are uncontroversial in their interpretation, in this review we have identified findings for which there is considerable consensus regarding both their robustness and their contribution to our understanding of spoken word production. Finally there are, of course, a great number of exciting results that we will not discuss. This is in part due to space limitations, but also because our goal is not to carry out a comprehensive review of the literature but, instead, to focus on the most well-established findings from the cognitive neuropsychological literature on spoken word production.

PROGRESS: 1984–2004

Of the seven issues identified from Ellis (1985), we consider that significant progress has been made in understanding the following four: (1) the distinction between word meaning and word form, (2) grammatical category distinctions at

the level of the phonological output lexicon, (3) the representation of morphologically complex words at the level of the phonological lexicon, and (4) questions of activation dynamics; the role of feedback, in particular. We consider that significant progress has also been made on two additional topics: (5) the distinction between lexical form and lexical syntax, and (6) the distinction among lexical categories at the level of phonological output lexicon (Table 1).

The basic architectural organisation

In the past 20 years, a basic focus of research interest has been to determine which of the many aspects of our word knowledge actually correspond to neurally differentiated distinctions that are respected during the course of lexical selection.

Word meaning/word form

Perhaps the most fundamental of lexical distinctions is the one between the meaning of a word and its phonological form. Psycholinguistic researchers have examined whether there are distinct lexical representations for a word's meaning and its form or whether these (and other) aspects of word knowledge are stored together under a single lexical entity (Forster, 1976; Levelt, 1989). Cognitive neuropsychological evidence has made a significant and unique contribution to answering this question.

The critical pattern of neuropsychological evidence indicating a representational and processing distinction between word meaning and word form is the following: *semantic errors in spoken naming in the face of intact word comprehension* and, additionally informative (although not obligatory) is *the absence of semantic errors in written naming*. This pattern is exemplified by the cases of RGB and HW reported by Caramazza and Hillis (1990; see also Basso, Taborelli, & Vignolo, 1978; Miceli, Benvegnú, Capasso, & Caramazza, 1997; Nickels, 1992; Rapp, Benzing, & Caramazza, 1997). For example, RGB orally named a picture of celery as "lettuce" but in written naming produced CELEY; similarly a picture of a finger was orally named as "ring" but

spelled FINGER. As indicated in Table 2, RGB and HW were 100% correct in their comprehension of written and spoken words, yet they produced a large proportion (26–32%) of semantic errors in oral reading and naming. In contrast, in written naming neither of these individuals produced semantic errors.

This pattern can be understood within a functional architecture in which there is a distinction between word meaning (lexical semantics) and word form (phonological lexicon), if we assume that the neurological insult has affected the phonological lexicon or access to it. The reasoning is as follows. Errorless performance in written and spoken word comprehension tasks indicates that lexical semantics are intact. Furthermore, the fact that written spelling is free of semantic errors is additional and compelling evidence that word meaning has been adequately processed. Having established intact word comprehension, the spoken naming difficulties indicate a deficit in processing some aspect of the spoken forms. The fact that semantic errors (rather than sound-based errors) are produced allows us to reject, with some confidence, the possibility that the source of the spoken naming errors is a post-lexical impairment affecting speech production. This is because it is difficult to imagine a deficit affecting purely sound-based processing that would yield only semantic errors. In this way, the pattern clearly reveals the independence of word form and word meaning.

Additional evidence is the complementary dissociation—access to intact word forms in the

face of severely impaired or absent lexical semantics. Specifically, there are cases of individuals who can read irregular words despite showing little or no evidence of understanding them (Bub, Cancelliere, & Kertesz, 1985; Cipolotti & Warrington, 1995; Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Coslett, 1991; Funnell, 1983; Hillis & Caramazza, 1991; Lambon Ralph, Ellis' & Franklin, 1995; Lambon Ralph, Ellis, & Sage, 1998; McCarthy & Warrington, 1986; Raymer & Berndt, 1996; Sartori, Masterson, & Job, 1987; Schwartz, Saffran, & Marin, 1980; Shallice, Warrington, & McCarthy, 1983; Wu, Martin, & Damian, 2002). In some cases, these individuals are also unable to correctly name the words from a picture or object stimulus (e.g., Hillis & Caramazza, 1991; Wu et al., 2002). The fact that the words are irregular makes it unlikely that they are read solely via knowledge of the systematic (or regular) relationships between graphemes and phonemes. It indicates that, instead, the word forms are recovered from the phonological lexicon either bypassing semantics or on the basis of incomplete semantic information (Hillis & Caramazza, 1995a). In either case, the striking difference observed between the paucity of lexical semantics and the integrity of lexical phonological information supports the conclusion of the independent representation of lexical semantics and lexical form.

Word form/word syntax

Another fundamental issue regarding lexical representation concerns the relationship between knowledge of word forms and word syntax (the grammatical properties of words). One question is whether word form and word syntax are independently represented. And, if they are, what is the processing relationship between these components of word knowledge in the course of lexical selection?

With regard to a possible distinction between word form and word syntax, the critical evidence has been the reports of individuals who display *intact knowledge of a word's grammatical properties despite being unable to recover the phonological form of the word*. A particularly clear example of this

Table 2. RGB and HW's performance in oral and written naming

		RGB	HW
Spoken	Correct	68%	65%
	Semantic ^a	32%	26%
	Omissions/Unrecognisable	0%	9%
Written	Correct	94%	91%
	Semantic ^a	0%	0%
	Omissions/Unrecognisable	6%	9%

^aIncludes definitions, morphological errors and nonwords recognisable as semantic errors; e.g., [skid](squid) for octopus.

pattern is the case of Dante, reported by Badecker, Miozzo, and Zanuttini (1995; see also Henaff Gonon, Bruckert, & Michel, 1989; Miozzo & Caramazza, 1997; Shapiro & Caramazza, 2003a; Vigliocco, Vinson, Martin, & Garrett, 1999). In one experiment Dante was asked to produce 200 single spoken words in picture naming and sentence completion tasks. He was able to correctly name only 56% of these items. For each of the 88 items he was unable to name, he was asked (at the time at which he was unable to name the item) to make a number of forced-choice judgments designed to evaluate his access to the word's grammatical and phonological properties. Specifically he was asked to make forced-choice judgments about grammatical gender (masculine/feminine), word length, first letter, last letter and rhyming (e.g, does it rhyme with word X or word Y). As indicated in Table 3, Dante was 98% accurate with gender judgments but his performance was no different from chance on the judgments that concerned the form of the word. That is, Dante was able to access a word's syntax although he was unable to recover its phonology. His inability to access word phonology was indicated both by his inability to name the word, and his inability to make above-chance judgments regarding form features. Furthermore, the authors determined that the failure in making judgments regarding phonological form could not be attributed to lack of understanding of the tasks themselves as Dante was accurate in making these same phonological judgments for words that he could name.¹

This pattern of performance clearly indicates that word syntax and word form are represented with sufficient neural independence that they can be selectively affected by neurological damage. This evidence of the independent representation of word form and word syntax quite naturally leads to the question of the processing relationship between the two. The current debate on this topic can be described as "the lemma dilemma."

Table 3. *Dante's accuracy on forced-choice questions on trials where he could not generate the target word (N = 88) (data combined from picture-naming and sentence completion tasks)*

	% correct
Grammatical gender	98
Word length	50
First letter	53
Last letter	47
Rhyming word	48

There are two major positions on the question. The position of Levelt and colleagues as well as others (Dell, 1986, 1990; Garrett, 1980; Kempen & Huijbers, 1983; Levelt, 1989, 1992; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992; Roelofs, Meyer, & Levelt, 1998) is that there is an independent level of lexical representations, referred to as lemmas, that represent or are linked to grammatical features. According to this position, lemmas are abstract, amodal representations that include or provide access to a word's grammatical features. Furthermore, and central to the claim, is the proposal that lemmas are the gatekeepers to a word's form and, as such, must be accessed prior to retrieval of the spoken (or written form) (Figure 2a). Within the cognitive neuropsychological literature the notion of abstract, lexical-grammatical representations is supported by evidence that certain individuals suffer from difficulties that are post-semantic yet pre-formal. For, example, there are the cases where a morphological deficit affects all input and output modalities in a very similar manner (Badecker, Rapp, & Caramazza, 1995). This can be explained by assuming that a (disrupted) morphological process operates over lexical representations that are shared across input and output, spoken and written modalities. The fact that these representations are shared across modalities indicates that they are abstract and amodal. Also thought to be

¹ Furthermore, the pattern reported in Table 3 was also observed for the subset of items for which grammatical gender cannot be predicted by the final segment of the word (i.e., nouns ending in/o/that are feminine and nouns ending in/a/that are masculine; nouns ending in/e/,/i/, and/u/that can be either masculine or feminine).

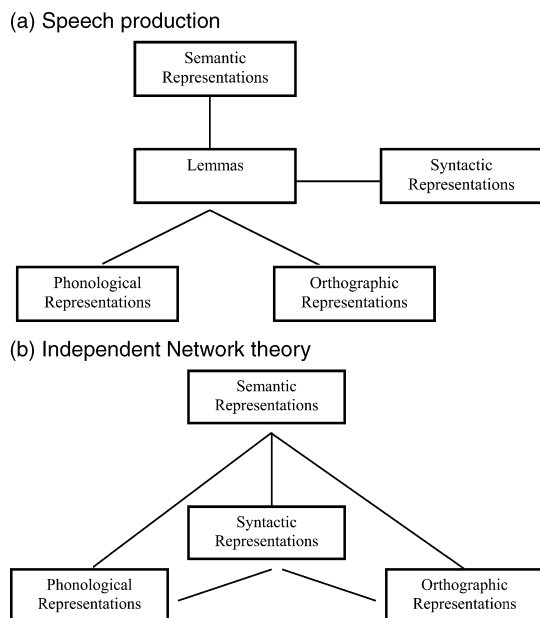


Figure 2. Schematic of lemma theories of (a) speech production and (b) the Independent Network theory of Caramazza (1997b).

supportive of the lemma proposal are cases in which morphological processing of both regularly (e.g., walked) and irregularly inflected forms (e.g., went) is affected (see below; see also Allen & Badecker, 1999, for evidence and arguments from the psycholinguistic literature). The rationale in these cases is that for regular and irregular forms to be similarly affected they must share a common and presumably abstract, amodal lexical representation.

However, even prior to 1984, there was scepticism regarding the notion of modality-neutral lexical representations (Allport & Funnell, 1981; Butterworth, 1983). This scepticism has continued and Caramazza (1997) and Caramazza and Miozzo (1997) have more recently claimed that an additional amodal lexical representational level is unnecessary. They have argued that the empirical facts can be understood without positing lemma representations. They propose, instead, that a word's grammatical features are linked to its form and that, in contrast to the lemma position, word syntax is accessible either from form

or (depending on the type of grammatical feature) from semantics (Figure 2b).

There are two major disputed questions in this debate: First, whether or not there is an amodal, *lexical* level of representation that links to both word form and syntax. Second, whether word syntax must be accessed prior to word form. Although in the next section we discuss some additional evidence that is relevant to this debate, a full review of the arguments and relevant evidence is beyond the scope of this paper; instead, we refer the interested reader to additional papers (e.g., Caramazza, 1997; Caramazza & Miozzo, 1997, 1998; Levelt et al., 1999; Rapp & Caramazza, 2002; Roelofs et al., 1998).

Regardless of the eventual resolution of these questions, what is clear from the evidence is that word form and word syntax are independently represented. Thus, the findings we have reviewed concerning the basic organisation of the architecture indicate a fairly robust consensus that the word production system consists (at a minimum) of independent semantic, syntactic, phonological (and orthographic) components.

The organisation of the speech (phonological) output lexicon

In addition to the progress that has been made in understanding the independent components of the lexical system, there have also been significant advances specifically in understanding the organisation and representational content of the phonological output lexicon itself.

Grammatical category distinctions

A number of cases of naming difficulties that disproportionately affect one grammatical category (nouns, verbs, or function words) have been reported. These deficits have manifested themselves in both comprehension and production, or selectively in comprehension or production, and within production in both written and spoken naming or selectively in spoken or written naming (see Rapp & Caramazza, 2002, for a review). These patterns clearly indicate that

grammatical category plays a role at some point in the word production process. However, the persistent challenges have been: (1) to determine if these selective deficits are truly grammatical rather than artifactual, and (2) if grammatical, to establish the level/s in spoken naming process at which grammatical category distinctions are represented.

With regard to the issue of the grammatical nature of the deficits, there have been a number of proposals that attribute the reported deficits to nongrammatical factors that are often correlated with grammatical category. It has been suggested that what may actually be relevant is some semantic variable such as abstractness/imageability (see Bird, Howard, & Franklin, 2000; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998; but see Shapiro & Caramazza, 2001, for a critical commentary).

There have, however, been a number of lines of evidence that at the least, not all cases of apparent grammatical category deficits can be explained by semantic factors. Specifically, noun/verb dissociations have been documented even when factors such as abstractness have been controlled across grammatical categories (e.g., Berndt, Haendiges, Burton, & Mitchum, 2001, 2002). Additional evidence against a strictly semantic account are the reports of category-specific morphological deficits (Laiacina & Caramazza, 2004; Shapiro & Caramazza, 2001, 2003b; Shapiro, Shelton, & Caramazza, 2000; Tsapkini, Jarema, & Kehayia, 2001). For example, JC (Shapiro & Caramazza, 2001) had more difficulty producing the plural of nouns (*guide* → *guides*) than the third person of their verb homophones.² The fact that the grammatical category difficulty was specifically morphological makes a semantic account of the grammatical category dissociation unlikely.

With regard to the question of the level of processing at which grammatical category distinctions are represented, one possibility is that grammatical category is an organising feature at a central,

amodal level of representation (such as the lemma level) that is shared in spoken and written output, and possibly also for comprehension and production. Such a level would most likely play a key role in sentence production and morphology. Another possibility is that grammatical category distinctions are modality-specific and represented at the level of phonological (and orthographic) form, either exclusively, or in addition to being represented at a central, amodal level.

One of the most compelling lines of evidence indicating that grammatical category organisation is both nonsemantic and active beyond a central, amodal level are the reports of grammatical category deficits that are modality specific. In these cases there is a selective deficit in producing words of one grammatical category and the deficit is restricted to either the spoken or written modality. Caramazza and Hillis (1991) reported two such cases: one exhibited selective difficulty in producing spoken verbs versus spoken nouns but had no particular difficulty with written verbs or nouns; the other case had difficulty producing written verbs versus nouns, with sparing of spoken verbs and nouns (for other cases of modality-specific noun/verb deficits, see also Baxter & Warrington, 1985; Berndt & Haendiges, 2000; Hillis & Caramazza, 1995b; Rapp & Caramazza, 1998).

In addition to cases such as these there are also cases of *single* individuals who exhibit a double dissociation of grammatical category by modality. A number of these have exhibited difficulty with the open class vocabulary in spoken production and the closed class vocabulary in written production (Assal, Buttet, & Jolivet, 1981; Bub & Kertesz, 1982; Coslett, Gonzales-Rothi, & Heilman, 1984; Lecours & Rouillon, 1976; Lhermitte & Derouesne, 1974; Patterson & Shewell, 1987; Rapp et al., 1997), prompting their characterisation as “oral Wernicke vs. written Broca” (Assal et al., 1981). One of the most striking dissociations of grammatical category

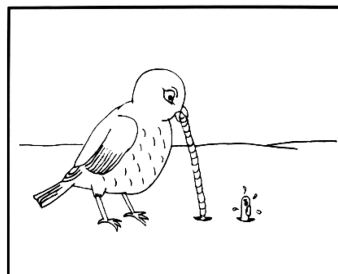
²Note, this was also the case even for nonwords—“this is a wug; these are ___” was less difficult than “these people wug, this person ___.” The reverse pattern was exhibited by JR (Shapiro & Caramazza, 2003b).

by modality is that of KSR (Rapp & Caramazza, 2002; see also Hillis & Caramazza, 1995b) who exhibited a double dissociation of nouns/verbs by modality. As indicated in Table 4, in single word picture naming tasks, KSR had more difficulty producing spoken nouns than verbs and more difficulty producing written verbs than nouns. Examples of his responses when asked to say or write a sentence are shown in Figure 3, where it can be seen that, for example, in response to a picture of a girl pushing a wagon he writes “the girl is actions a wagon,” but he says “The girl is holding the /b a l g/.”

The pattern of modality-specific, grammatical category impairment is compelling because the integrity of the grammatical category in one modality indicates that the deficit cannot be an artifact of some semantic variable. Furthermore, the pattern also indicates that some grammatical category distinction must originate at a post-semantic, modality-specific level of processing. Typically these deficits are interpreted as revealing that the phonological and orthographic lexicons are organised in such a manner that neurological damage can selectively affect the retrieval of words from one grammatical category. This conclusion is not, of course, inconsistent with an architecture in which earlier levels of representation are *also* organised in a manner that respects grammatical category distinctions.

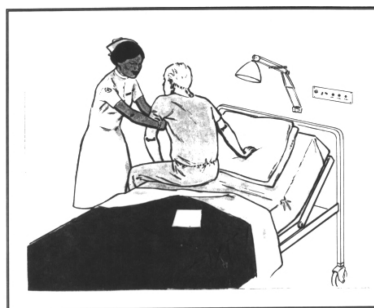
The relevance of these data to the lemma dilemma is that they are problematic for the view that grammatical category distinctions are present only at a modality-independent level of representation, as has been suggested by certain

lemma-based accounts (Dell, 1990; Levelt, 1989; Levelt et al., 1999; Roelofs, 1992; Roelofs et al., 1998). However, they may be accommodated within a lemma-based account if



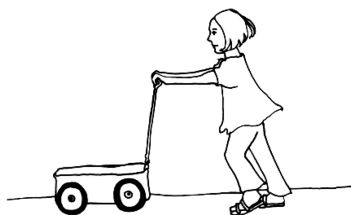
“The /p r e d/ is eating a man.”

The bird is eating the worm.



“The nurse is helping the man.”

The nurse is happening the man.



“The girl is holding the /b a l g/.”

The girl is ach/actions a/ a wagon.

Table 4. Distribution of KSR’s responses on spoken and written naming of nouns and verbs

	Spoken noun	Spoken verb	Written noun	Written verb
Correct	71	89	93	55
Other word	10	6	1	14
Nonword	17	2	3	4
Omission	1	0	1	7
Morphological	1	2	2	11
Other word + morphological	0	0	0	7

Figure 3. KSR’s written and spoken naming of target pictures.

the modality-specific, grammatical category distinctions are represented in the connections between the lemma and form levels. Nonetheless, Rapp and Caramazza (2002) suggest that more detailed aspects of KSR's performance represent a challenge for the lemma-based accounts (see also Caramazza & Miozzo, 1998).

Lexical category distinctions

In addition to post-semantic grammatical category distinctions, there have been claims of additional post-semantic category-specific deficits that, presumably, reveal the organisation of the phonological lexicon. These have involved a number of categories, including: abstract/concrete words (Franklin, Howard, & Patterson, 1995), semantic categories (e.g., body parts, fruits and vegetables, colours, etc.; Beauvois, 1982; Dennis, 1976; Hart, Berndt, & Caramazza, 1985), letter names (Goodglass, Wingfield, Hide, & Theurkauf, 1986), number names (McCloskey, Sokol, & Goodman, 1986), and proper nouns (see below). Among these, perhaps the strongest case has been made for the proper/common noun distinction. At any rate, since the critical pattern of evidence is essentially the same regardless of the category, proper nouns will serve as a representative case. These lexical category distinctions are assumed to represent a further differentiation of the noun component of the phonological lexicon (see Figure 5 on p. 57).

The critical evidence takes the form of *selective difficulty in naming proper but not common nouns in the face of intact comprehension of proper nouns*. This pattern is exemplified by the case of PC reported by Semenza and Zettin (1988; see also Lucchelli & DeRenzi, 1992; McKenna & Warrington, 1978; Semenza & Zettin, 1989; Warrington & McCarthy, 1987). PC was 100% ($n = 303$) correct in his naming of pictures, real objects, and naming to definition of items from the categories of vegetables, fruits, body parts, colours, letters, transportation, pasta, furniture, and numbers, as well as adjectives and verbs. In contrast, his accuracy in naming proper names (people, cities, rivers, countries, mountains) in

response to picture stimuli, maps, or definitions was extremely poor, with an accuracy of only 2% ($n = 119$). Also contrasting with his poor naming of proper nouns was the observation that his comprehension of the names and pictures was apparently intact (97% correct, $n = 119$). For example, in response to a picture of the then Italian prime minister, although PC was unable to name him, he correctly said: "he is the first socialist holding this position in our country."

The fact that comprehension is intact indicates that the naming deficit does not arise at the semantic level, revealing a differentiation between proper and common nouns either in the organisation of the phonological lexicon itself, or in the processes involved in accessing proper and common names from the phonological lexicon. One consistent concern with this interpretation has been the possibility that proper nouns are more vulnerable to damage than common nouns, not because they are independently represented, but simply because they are lower in frequency. However, the fact that PC, for example, was able to name very infrequent common nouns but no proper nouns (even frequent ones) renders such an account unlikely. The evidence that would most readily speak to this concern would be cases of selective sparing of proper nouns. Such cases have been reported (Cipolotti, 2000; Cipolotti, McNeil, & Warrington, 1993; McKenna & Warrington, 1978; Schmidt & Buchanan, 2004; Semenza & Sgaramella, 1993), although they all have been somewhat problematic as they have involved only extremely impaired individuals who usually could be tested only in the written modality (see Schmidt, Buchanan, & Semenza, 2003, for a review). Despite these limitations, although BWN (Schmidt et al., 2003) could only produce written responses, he was 100% correct with proper nouns but only 50% correct with common nouns. With common nouns, he produced either semantic errors (*clown* → *man*) or omissions, despite communicating that he knew their meaning.

If the proper/common noun dissociations indicate a representational distinction at the level of the phonological output lexicon, then we would

expect (as in the case of post-semantic, grammatical category deficits) to observe modality-specific deficits affecting proper and common nouns. One such case was recently reported by Cipolotti (2000). This individual showed proper name superiority (just for country names) in the spoken modality (100% for country names vs. 30% for objects) but not the written modality (100% correct on both country names and objects). Such a pattern supports the differentiation of proper vs common nouns at the level of the phonological lexicon. As was the case for grammatical category organisation, this does not, however, preclude the differentiation of common and proper nouns at higher levels such as within the semantic system and, indeed, there have been cases exhibiting selective impairment of conceptual knowledge for proper names that support this (Lyons, Hanley, & Kay, 2002; Miceli, Capasso, Daniele, Esposito, Magarelli, & Tamaiuolo, 2000).

Given the quite robust evidence for a distinction between proper and common nouns at the level of the phonological lexicon one can, quite naturally, wonder what purpose it would serve. Thus, whereas the specification of grammatical category at the level of form may play a role in sentence production and productive morphological processes, the functional role of a proper/common noun distinction is less obvious. It has been suggested (Semenza & Zettin, 1989) that the distinction may have its origins in differences in the learning of the two categories of words. Specifically, Semenza and Zettin (1989) pointed out that unlike common nouns, proper nouns are referring expressions that are arbitrary in that they apply only to a specific referent and do not imply any particular set of semantic attributes. Some support for the relevance of this fact is that several individuals with selective difficulties with proper names also had difficulty in learning arbitrary paired associates (Hittmaier-Delazer, Denes, Semenza, & Mantovan, 1994; Lucchelli & De Renzi, 1992; Semenza & Zettin, 1989; but see Saetti, Marangolo, DeRenzi, Rinalidi, & Lattanzi, 1999). Clearly, however, the underlying basis for lexical category distinctions at the level of

the phonological lexicon requires further investigation.

Morphological decomposition

Are morphologically complex words stored in memory as whole word representations or in terms of their constituent morphemes? This single question has dominated psycholinguistic work on the mental lexicon and, fortunately, it is an issue regarding which cognitive neuropsychological evidence has been particularly informative.

There are a number of possible distinctions that can be considered and that add to the complexity of the question. First, there are the possible distinctions between levels of representation. The question of morphological composition certainly refers to the representation of morphologically complex words at the level of phonological form. However, if one assumes an abstract level of lexical representation such as the lemma, the question can also refer to this representational level as well. Another distinction is that between regular and irregular morphology. Compositionality at the level of form is not equally plausible for all morphologically complex words. In English, for example, although there is a highly regular compositional pattern that characterises the past tense of the vast majority of verbs (e.g., walk-walked), there are also the more idiosyncratic patterns of the so-called irregular verbs (e.g., tell-told; is-was; hit-hit), which render them less obvious candidates for morphological composition at the level of form. The nature of the distinction between regular/irregular morphological patterns has been the focus of particularly intense debate over the past 20 years (for recent reviews, see Marslen-Wilson & Tyler, 1998; McClelland & Patterson, 2002; Pinker & Ullman, 2002). Finally there is the distinction between inflectional and derivational morphology: What may be true of inflectional morphology need not be the case for derivational morphology. With regard to questions of composition/decomposition, these three distinctions are largely independent of one another. That is to say, evidence for decomposition for one category does

not necessarily have implications regarding another. As a result, a rather diverse set of proposals has been put forward. Rather than attempting to review this very considerable body of work, we focus here on those patterns for which the evidence of compositionality is clearest, namely for *regularly inflected words at the level of phonological form*.

The general pattern that strongly supports the claim of decomposed phonological representations of inflected words is the following: *morphological errors in spoken production in the context of intact comprehension of morphological contrasts*. Intact comprehension assures that the morphological deficit in fact arises at the level of the phonological output lexicon and not at a more central level of morphological representation and processing. The third element of this pattern is *evidence ruling out nonmorphological (semantic or form-based) interpretations of the errors* (e.g., Pillon, de Partz, Raison, & Seron, 1991).

There have been a number of different performance configurations that generally fit this pattern and that have supported the notion of morphological decomposition at the level of lexical phonological form. Inflected neologisms constitute one such case. Certain individuals have been reported who produce neologisms for the stem of a word that is otherwise appropriately inflected (e.g., “he’s really *knawling* over me” (Buckingham & Kertesz, 1976); “she /*wiksəz*/” (Butterworth & Howard, 1987); “tuto il *ternessico* che mi aspetta” Semenza, Butterworth, Panzeri, & Ferreri, 1990; see also Buckingham, 1981; Caplan, Keller, & Locke, 1972). Although these errors are extremely compelling, one of the difficulties has been in clearly establishing that the errors do not represent a phonological deformation of a whole-word form that diminishes towards the end of the word. Furthermore, it has often been difficult to evaluate comprehension of morphological contrasts in these cases (e.g., Semenza et al., 1990, reported individuals with significant comprehension impairments; similar comprehension impairments were found for 2/5 cases reviewed by Butterworth & Howard, 1987).

An especially compelling pattern of performance that has been informative with regard to the question of morphological decomposition at the level of phonological form is the production of morphologically illegal combinations of stem and affix (e.g., *blackness* → *blackage*). Such combinations are surely not stored in the lexicon and must, therefore, be the result of morphologically based compositional processes. FS (Miceli & Caramazza, 1988) produced errors of this type, for example, *resisteva* (he was resisting) was produced as *resistire* (correct stem with the infinitival form for verbs of the 3rd conjugation), as did cases reported in Semenza et al. (1990) (e.g., *fratellanza* [brotherhood] → *fratellismo*) (see also Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995). One case that clearly presents all of the elements of the critical pattern identified above is that of SJD, reported by Badecker and Caramazza (1991). In spontaneous speech and oral reading, SJD produced morphologically illegal errors such as *poorest* read as *poorless*, *youthful* as *youthly*, *discussing* as *discussionly*. Although SJD did produce some phonological errors, a phonological basis for the morphologically illegal errors was ruled out because SJD produced morphological errors only for inflected forms (e.g., links, teas) and not for homophonic unaffixed forms (e.g., lynx, tease) (see Table 5). Furthermore, a semantic or input locus for these errors was ruled out because many of the illegal morphological combinations were accompanied by clearly adequate definitions (e.g., *cloudless* → *cloudness*, *it means if*

Table 5. Percentage of total responses in SJD’s reading aloud of matched sets of affixed/unaffixed homophones (examples of each potential error type on each list are shown in parentheses)

	Affixed homophones (e.g., TEAS)	Unaffixed homophones (e.g., TEASE)
Correct	50	85
Morphological error (bowled → bowl; lynx → link)	42	0
Phonological error (frays → prays; bread → breast)	8	15

the sun is clear, with no clouds at all). Finally, additional evidence of a form-based locus of impairment was that regularly inflected forms were affected (60% correct) while irregularly inflected were not (92%) and, in fact, these behaved similarly to uninflected forms (90%). This implicates a level of representation—such as phonological form—where regularly and irregularly inflected forms are most likely to be represented in a distinct manner.

The evidence of decomposed phonological forms implies that there are morphological processes that manipulate morpheme-sized phonological representations in composing inflected forms. Whether these morphological processes are themselves modality-specific or whether they are amodal and simply manipulate modality-specific morphemic representations is unclear from the available data. In either case, it would be predicted that there might be cases of modality-specific morphological deficits; that is, we should expect to find cases in which the patterns reported above are present in either the written or spoken modality with intact morphological composition in the other modality. There is some evidence that this may indeed be the case. Berndt and Haendiges (2000) described an individual with selective difficulties in producing written verbs who produced morphological errors in writing but never in speaking (see also the data in Table 4 above; Rapp & Caramazza, 2002).

It is important to be clear that the finding of form-level morphological decomposition is not at odds with, nor does it preclude, there being compositional morphological processes operating at a more abstract level. In fact there are a number of lines of evidence that indicate that this may indeed be the case (see Allen & Badecker, 2001, for a review of evidence from spoken production; see also Marslen-Wilson & Tyler, 1998, 2005, for reviews of research in comprehension and production). Badecker (1997; see also Badecker & Caramazza, 1987) reported the case of FM, who produced a large number of morphological errors and significantly higher error rates on both regularly (e.g., *asked*) and irregularly (e.g., *ate*) inflected verbs compared

to uninflected verbs (e.g., *ask*, *eat*). The fact that both regular and irregular forms were similarly affected (in contrast to the pattern exhibited by SJD described above) suggests that the deficit was at a level at which both are similarly represented. This would seem to exclude the phonological level. Furthermore, Badecker (1997) argued that a simple semantic account of these errors is ruled out by asymmetries in FM's productions. In particular, he produced many errors where an inflected form was replaced by its corresponding base form (e.g., *asked* → *ask*), but few errors where the reverse occurred (e.g., *ask* → *asked*). If FM's errors were based purely on semantic similarity, there should be no such asymmetry; the semantic distance involved in both errors is identical. Instead his errors are apparently influenced by the compositional structure of inflected forms, whether regular or irregular. This points to an abstract level of representation where morphological processes deal with abstract morphosyntactic structures in a manner that is "blind" to differences in surface form (e.g., [talk] + past is handled similarly to [eat] + past). (For other lines of neuropsychological evidence that support a level of morphological representation that is form-independent, see Laine et al., 1995.) Along somewhat similar lines there is the evidence that morphological representations and processes may be shared across modalities. This includes individuals with deficits that affect the processing of both regularly and irregularly inflected forms relative to uninflected forms, in both comprehension and production, across written and spoken modalities (Badecker et al., 1995). It should be noted, however, that the neuropsychological evidence for a strictly abstract and/or amodal level of morphological representation is scarce and not without its limitations. Important in this regard is the fact that there have been no reports of individuals who make morphological errors who do not also have phonological deficits (Miceli, Capasso, & Caramazza, 2004), suggesting an especially close link between morphology and form.

In summary, with respect to regularly inflected forms, there is clear support for morphological

decomposition at the level of the speech production lexicon. Other patterns of cognitive neuropsychological evidence suggest additional levels of morphological representation, although the neuropsychological evidence is more controversial on this point. The overall picture may be consistent with a distinction between decomposed lexical phonological representations on the one hand and morphological processes that deal with abstract morphosyntactic structures on the other. This type of distinction would seem to map naturally onto the lemma/lexeme (form) distinction that has been proposed; but, as we have indicated earlier, this conclusion has been vigorously contested (Caramazza, 1997). Clearly, the resolution of this set of intimately inter-related issues concerning the syntactic and morphological nature of lexical representation and processing will be one of the major challenges facing future cognitive neuropsychological research.

Activation dynamics

The spoken word production architecture developed to this point has been largely a static one, as there has been little discussion of the temporal attributes of processing. However, the issue of activation dynamics is clearly an important one in the context of spoken word production and in this section we focus on the progress that has been made in understanding the roles of feedback and cascading activation in spoken word production.

Feedback and cascading activation

The debate on interactivity in spoken word production has been dominated by two sets of positions—the discrete and the interactive. While there are a number of variants within these two sets of positions, we take the proposal of Levelt and colleagues (Levelt, Schriefers,

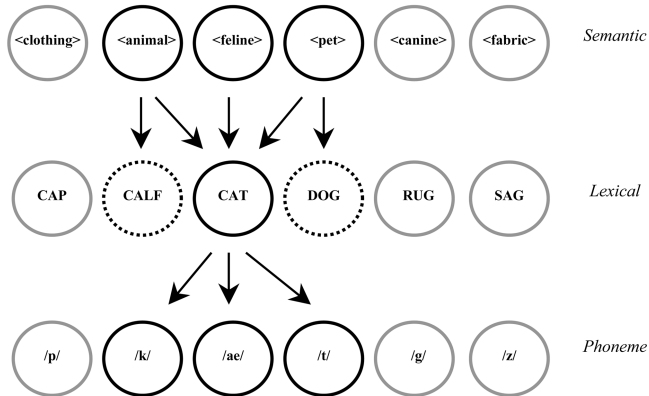
Vorberg, Meyer, Pechmann, & Havinga, 1991a; Levelt et al., 1999) to be representative of the highly discrete view and that of Dell and colleagues (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997) to be representative of the highly interactive view. Both positions assume the general two-stage framework depicted in Figure 1, with Stage 1 referred to as *lexical selection* and Stage 2 as *phonological encoding*.

According to the highly discrete position, processing proceeds in a strictly feedforward direction, with the selection of an item at each level (e.g., semantic, lexical and phonological) taking place before activation is passed on to the subsequent level (Levelt et al., 1991a). Within such an architecture (see Figure 4a), Stage 1 begins when semantic information regarding the target produces activation of the target and its semantically related competitors at the semantic and lexical levels. This stage of lexical selection ends when a single lexical unit is selected; competing lexical units are not allowed to pass on their activation to the phoneme level. Then, during Stage 2, only the phonemes for the selected lexical unit are activated and selected.³

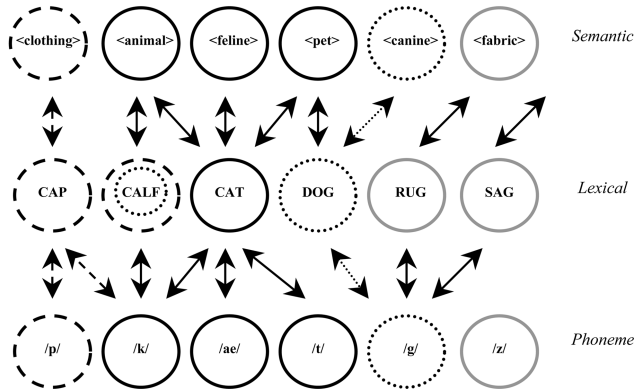
According to an interactive position (see Figure 4b), Stage 1 begins (as in the discrete architecture) when semantic information regarding the target produces activation of the target and its semantically related competitors, and Stage 1 continues as all of the activated lexical units pass on activation to the phoneme level. Furthermore, activation throughout Stages 1 and 2 involves not only a forward flow of activation but also a backward flow between the phonological and lexical levels as well as between the lexical and semantic levels. Stage 1 ends with the selection of the most active lexical unit; however, within this framework, selection means only that the activation level of the selected unit is raised above that of its competitors; competitors are allowed to pass on their activation. During

³ As discussed above, Levelt and colleagues' position with regard to lexical representation is that there are two levels of lexical representation—lemmas and lexemes, prior to the phoneme level. They assume that only a single selected lemma will activate its corresponding lexeme, and only this lexeme can pass on activation to the phoneme level. Despite this additional level/stage, it is not obvious that this changes any of the predictions we will discuss here.

(a) Highly discrete account



(b) Highly interactive account



(c) Restricted interaction account

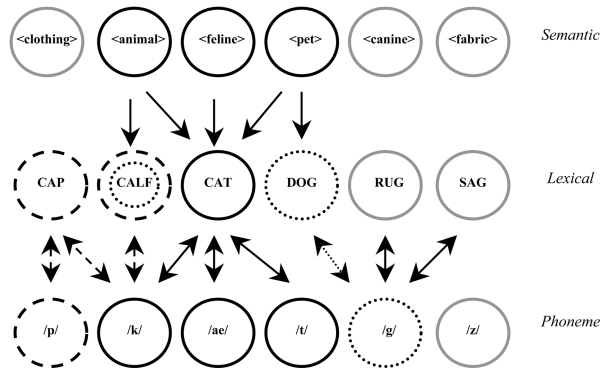


Figure 4. (a) Highly discrete, (b) highly interactive, and (c) restricted interaction accounts of spoken word production for the target word “cat”. Dotted lines and units show activation due to semantic overlap with the target; dashed lines and units show activation due to phonological overlap with the target. (Concentric circle denote units activated by both semantic and phonological overlap. Greyed-out units are not strongly activated by the target.)

Stage 2, processing at all levels continues until the end of the stage, at which time the most active phoneme units are selected.

These two positions are similar in terms of the representational types they assume and their commitment to a two-stage framework. In addition, they share the assumption that both the target and its semantic competitors are active during Stage 1 lexical selection. They differ primarily in that the interactive position assumes cascading activation and feedback throughout the entire process. Prominent among the various lines of evidence that have been considered in trying to adjudicate between these positions have been analyses of mixed errors and form-based errors.

Speakers sometimes produce a word that is related in meaning to a target word (e.g., *shirt* → *skirt*). A number of analyses of spontaneous and experimentally induced speech errors produced by both neurologically intact and neurologically injured individuals have indicated that these semantic errors show a higher degree of phonological similarity to the intended word than would be predicted by a highly discrete account (Blanken, 1998; Brédart & Valentine, 1992; Dell & Reich, 1981; Dell et al., 1997; Harley, 1984; Kulke & Blanken, 2001; Martin, Gagnon, Schwartz, Dell, & Saffran, 1996a; Martin, Weisberg, & Saffran, 1989; Rapp & Goldrick, 2000; but see Best, 1996; del Viso, Igoa, & García-Albea, 1991; Igoa, 1996; Levelt, 1983, 1992; Nickels, 1995). Similarly, analyses of both lexical (e.g., *mitten* → *muffin*) and nonlexical (e.g., *trumpet* → “*chirpet*”) form-based errors have indicated that lexical form-based errors occur at rates greater than would be expected in a highly discrete system (Baars, Motley, & MacKay, 1975; Best, 1996; Dell, 1986, 1990; Dell & Reich, 1981; Gagnon, Schwartz, Martin, Dell, & Saffran, 1997b; Harley, 1984; Humphreys, 2002; Nootboom, 2003, 2004; Stemberger, 1985; but see del Viso et al., 1991; Garrett, 1976; Nickels & Howard, 1995). This latter finding is referred to as the “lexical bias effect” as it suggests that

production system is biased to produce word outcomes.

Both mixed error and lexical bias effects are thought to require at least some form of feedback. Interactive theories account for lexical bias as follows: As activation passes from the lexical representation of a target (CAT) to its phonemes (/k//ae//t/), feedback connections send activation from these phonemes back to all lexical units that share phonemes with the target, including form-related neighbours of the target (e.g., HAT, BAT, MAT, RAT). These, in turn, activate their constituent phonemes, including those that are not shared with the target (/h/for HAT). These then reactivate their lexical level representations, creating “positive feedback loops” (Dell, 1986). Nonword responses (e.g., GAT) do not benefit from this type of support and, for that reason, when a disruption in processing occurs, the phonemes of the form-related neighbours of CAT will more successfully compete for selection than the phonemes of nonwords (i.e.,/h/will be a stronger competitor than/g/for the onset position).

With regard to the mixed error effect, the interactive architecture accounts for it by assuming that the feedback connections (from phonology to the lexical level and also from the lexical level to semantics) allow for interaction between semantic and phonological processes. Because of this, the mixed neighbours of a target (RAT) will be more active than other competitors that are either only semantically (DOG) or only phonologically (HAT) related to the target. As a result, all other things being equal,⁴ if an error arises in the course of lexical selection, a mixed neighbour is a more likely error than a semantic or phonological neighbor.

Mixed error and lexical bias effects cannot be readily accounted for within highly discrete architectures and their proponents have presented a number of arguments challenging the validity of these effects in neurologically intact individuals (e.g., attributing effects to speaker’s monitoring

⁴For example, the probabilities need to take into account the numbers of neighbours of the various types (see Rapp & Goldrick, 2000, for further discussion).

of their speech; Baars et al., 1975; Levelt, 1983, 1992; Levelt et al., 1999; Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991b; Nooteboom, 2003; Roelofs, 2004a, 2004b). It is beyond the scope of this paper to review and evaluate these arguments (see Rapp & Goldrick, 2000, 2004). We instead focus our discussion on the evidence from aphasic production that has been brought to bear on the question of interactivity in spoken word production.

There have been a number of analyses of aphasic errors that have attempted to determine whether or not mixed errors (Blanken, 1998; Dell et al., 1997b; Kulke & Blanken, 2001; Martin et al., 1996; Rapp & Goldrick, 2000) or form-based lexical errors (Best, 1996; Gagnon et al., 1997) occur at rates higher than would be expected by chance in a discrete architecture. Dell and colleagues (Dell et al., 1997b; see also Martin, Dell, Saffran, & Schwartz, 1994; Martin, Saffran, & Dell, 1996b; Schwartz & Brecher, 2000; Schwartz, Wilshire, Gagnon, & Polansky, 2004) used simulations to test the hypothesis that a wide range of patterns of spoken naming deficits could be accounted for within a highly interactive architecture. They showed that the fit between observed and simulated patterns was substantially better than the fit obtained for randomly generated patterns of errors. This success indicated that the evidence was generally consistent with the interactive two-stage account. In addition to the claims Dell and colleagues made regarding activation dynamics, they also made two other significant claims regarding the nature of the damage that gives rise to word naming deficits. First, they specifically argued that the fit between observed and simulated data was achieved by assuming that spoken naming deficits arise from global damage affecting all levels of the spoken production system (the globality assumption). Second, they further proposed that damage takes one of two forms, affecting either representational integrity (increased decay rates of the nodes throughout the system) or information transmission (noise on the connections between representational levels). Of these claims, the globality assumption

has generated the most controversy and has been weakened by a number of challenges (Caramazza, Papagno, & Rumel, 2000; Cuetos, Aguado, & Caramazza, 2000; Dell, Lawler, Harris, & Gordon, 2004; Foygel & Dell, 2000; Rapp & Goldrick, 2000; Rumel & Caramazza, 2000; Rumel, Caramazza, Shelton, & Chialant, 2000; see Dell, Schwartz, Martin, Saffran, & Gagnon, 2000, for a reply to some of these challenges). In contrast, the proposal that the specific nature of the damage (i.e., whether it affects representations, the connections between them, the rate of activation) may produce different effects is one which has also been put forward in different forms by a number of investigators (e.g., access/storage deficits, see Crutch & Warrington, 2001; Warrington & Shallice, 1979), and is a topic that will continue to be the focus of numerous research efforts.

Rapp and Goldrick (2000, 2004; Goldrick & Rapp, 2002) followed up on the work of Dell and colleagues. Rather than examining if the existing data are simply *consistent* with the highly interactive architecture depicted in Figure 4b, this work sought to determine the specific architectural features (e.g., feedback, cascading activation) that are *required* to account for a set of critical performance patterns. Through a series of computer simulation studies this work examined the predictions of theories that varied with regard to the degree of interactivity that was assumed. They examined simulations instantiating both highly discrete and interactive architectures, and also architectures of intermediate interactivity. Those with intermediate levels of interactivity included a two-stage architecture that assumed cascading activation but lacked feedback, and one that incorporated cascading activation and feedback but in which the feedback was limited. Specifically, in the latter architecture (referred to as the Restricted Interactivity Account, or RIA) there was feedback from the phonological to the lexical level, but not from the lexical level back up to semantics (Figure 4c). After an extensive series of analyses, Rapp and Goldrick concluded that of all the architectures they examined, the RIA

provided the best fit to the critical patterns of both the normal and aphasic data (but see Roelofs, 2004a, 2004b; Rumel et al., 2000). They claimed that with regard to the architecture of spoken word production “the important generalization is that although interaction is necessary, it is also true that interactivity is problematic as it increases beyond some optimal point” (p. 491).⁵

In addition to its theoretical implications, the work on activation dynamics also serves to underscore two more general points. One is the realisation that there is no atheoretical method for computing chance, rather that chance is simply the rate at which something would occur in some theory that does not include the feature of interest. For example, in the case at hand, chance is the rate at which mixed errors and form-related lexical errors would be predicted by a theory that does not include feedback. Once these rates are established, they can be compared to the observed rates. If they are at odds with one another, then the data represent a challenge to the theory that lacks the feature of interest. The second point is the increasing relevance of computer simulation to the development and testing of theories of spoken word production (see below, as well as Harley, 1993, 1995; Harley & MacAndrew, 1995; Laine, Tikkala, & Juhola, 1998; Plaut & Shallice, 1993; Wright & Ahmad, 1997). It is not surprising that questions of activation dynamics have led to extensive simulation work because the introduction of mechanisms such as feedback greatly increases the complexity of a theory. Given this, computer simulations can serve as an invaluable tool for clarifying the consequences of introducing activation dynamics into a theory and, therefore, the predictions of the different theoretical positions.

Summary: 1984–2004

In the above sections we have reviewed six questions on which, in our view, clear and significant

progress has been made over the last 20 years of cognitive neuropsychological research on spoken word production. As indicated earlier, there are many more exciting questions that have been investigated and important findings that have been reported than we have discussed; we have limited ourselves to highlighting the most reliable and robust of these that have had implications for fundamental aspects of our understanding of spoken word production.

Our review indicates that, arguably, in the last 20 years cognitive neuropsychology has made its strongest contributions to questions concerning the organisation and content of the phonological lexicon. These can be summarised schematically in Figure 5. The evidence reveals an internally complex, long-term memory system that encodes morpheme-based phonological representations that are organised in a manner that respects grammatical and (certain) lexical categories. Furthermore, research reveals that this lexicon is dynamic, that lexical items compete for selection with other items that are concurrently active, and that both top-down (semantic–word) and bottom up (phoneme–word) constraints are brought to bear on this competition. Presumably, these characteristics allow for the effective selection and composition of word forms that are required for sentence production.

Methodological points

A number of methodological observations emerge from this review. One concerns the sometimes critical role played by *written* spelling data in elucidating questions of *spoken* word production. An examination of the integrity of written language production often allows us to determine if effects of interest observed in spoken word production arise at modality-specific levels of representation and processing (e.g., the phonological lexicon) or at modality-independent levels (syntactic or semantic levels). When an effect is present in spoken production but absent in

⁵This conclusion is assumed to hold across a range of simulation implementations, e.g., whether the representations in the system are localist or distributed or whether the system is implemented as an attractor network or in some other class of activation spreading architecture.

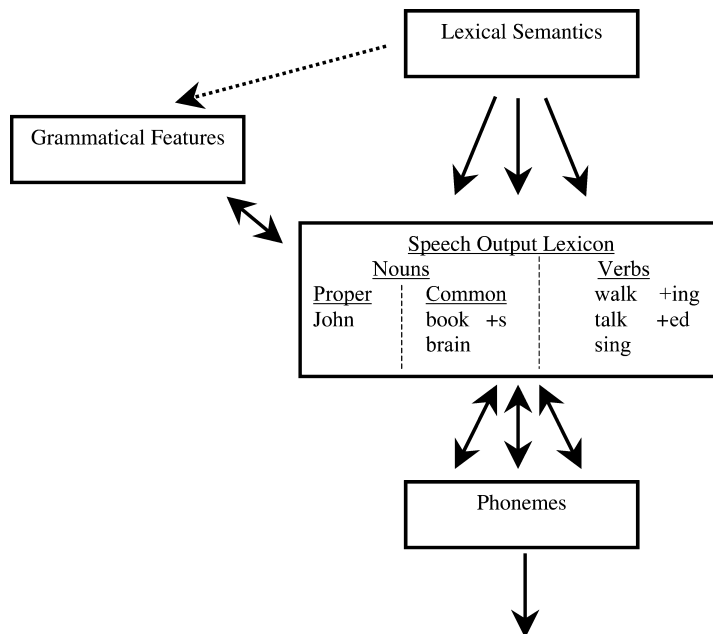


Figure 5. Framework for current theories of speech production, incorporating findings reviewed in the article. Multiple arrows between processing components denote cascading activation; double-headed arrows indicate feedback between components. Dashed line indicates uncertainty regarding relationship between lexical semantic representations and grammatical features.

written production, a case can be made for the modality-specific locus of the effect. In the cases reviewed above we see spelling data playing a critical role in the determination of post-semantic grammatical category distinctions as well as in the understanding that semantic errors can arise from disrupted access to the phonological lexicon from intact semantic representations.

Another point concerns the role of clinical categories and syndromes. Consistent with the insights of the cognitive neuropsychology pioneers of the 1970s and early 1980s, the progress that we have reported has not relied on clinical or syndrome characterisations of the individuals and/or their performance patterns. Instead, performance has been evaluated and interpreted relative to existing theories of intact language processing. This approach appears to have been highly productive, providing insights into both the content and organisation of the unimpaired spoken word production system, and an

understanding of the spoken word production deficits themselves.

Finally, it is worth noting that although dissociations and double dissociations have played an important role in the advances we have reported, this is not the only type of evidence that has been brought to bear on the questions of interest. For example, on the question of the separability of lexical semantic and form representations, although one element of the critical pattern was, indeed, the dissociation between word comprehension and spoken word production, the other critical element concerned *the types of errors* produced in spoken naming. Namely, it was the fact that the errors were semantic errors that was critical to establishing a lexical rather than post-lexical locus of impairment. Another example concerns the work on morphological decomposition. Here, most critical was the type of error that was produced, namely the illegal combinations of stems and affixes

(e.g., blackage, youthly). The argument was that these illegal combinations could not have been stored in the phonological lexicon and that, therefore, they must have been the product of compositional processes operating over morpheme-sized representations.

In sum, the last 20 years have been fruitful ones both with regard to the number of empirical findings with strong theoretical implications, as well as in terms of our understanding of a number of methodological issues. These advances provide reasonably firm foundations on which to construct an increasingly deeper and more detailed understanding of spoken word production. In the next sections, we discuss topics on which relatively less progress has been made and which, we anticipate, may occupy our research efforts in the upcoming years.

Spoken word production: Circa 2004 and beyond

If we consider Figure 5 as a summary of the current state of theorising, a number of deficiencies are immediately evident. First, it appears that progress has been made largely in our understanding of word selection, with considerably less progress having been made in understanding subsequent phonological processing stages. Second, the relationship between lexical processing and sentence processing is not indicated. Third, the relationship between word production and comprehension (one of the issues raised by Ellis, 1985) is not specified. Finally, there has been virtually no specification of the computational/representational machinery that allows words to be produced *in real time*. That is, not only are various aspects of activation dynamics (e.g., competition, inhibition, decay, buffering) underspecified, crucially, the representation of time itself (ordering, timing, and duration) is strikingly absent. We briefly discuss each of these topics, identifying the opportunities and challenges faced by cognitive neuropsychological research in these areas.

Phonological processing

Subsequent to word selection, there are a number of sound-based processing stages including (at a minimum): phonological encoding and buffering, articulatory planning, and motor execution. Given the pervasiveness of spoken production difficulties following left-hemisphere damage, it is quite alarming that there has been relatively little cognitive neuropsychological research on these topics. This is not to say that there have not been a number of excellent papers; however, these have been scarce relative to the number of opportunities available to study deficits arising at these levels, as well as relative to the progress that has been made in the neighbouring linguistic disciplines of phonology and phonetics.

There is a fairly broad consensus that there is a distinction between two basic types of phonological processes—sometimes referred to as lexical and post-lexical. Thus, it is generally assumed that a lexical phonological process (or set of processes) recovers the largely arbitrary lexical phonological representations from long-term memory. These representations are often assumed to be “abstract” in that they lack at least some of the predictable aspects of phonological structure (but see Bybee, 2001; Crompton, 1982). A subsequent post-lexical process (or set of processes) elaborates these lexical phonological representations to produce (more) fully-specified post-lexical phonological representations that contain the information necessary to engage subsequent articulatory and motor processes. Despite general agreement on this broad distinction, there is little agreement regarding the specific content of lexical and post-lexical phonological representations and processes.

To date much of the work directed at understanding the nature of phonological representations and the forces operating in the course of spoken word production has been influenced by linguistic work on markedness. Markedness refers to the typological distribution of sound structure; marked structures are found in few languages, while unmarked structures are found in many languages. If these notions are relevant for phonological processing, marked phonological

structures might be expected to be more difficult to process than unmarked structures. For example, it has been proposed (e.g., Clements, 1990) that segments within particular syllable positions (e.g., consonants within a syllable onset) are ordered in a systematic manner with certain orderings being more marked than others—a principle referred to as sonority. Following on from this, Romani and Calabrese (1998) and Romani, Olson, Semenza, and Granà (2002) reported that the sonority principle accounted for the pattern of errors observed in impaired spoken production and specifically concluded that sonority exerted an influence on post-lexical processing (i.e., articulatory planning). A preference for less marked structures has been generally found to be the case in a number of studies since the seminal work of Blumstein (1973), who studied the conversational production of a group of English-speaking aphasic individuals (see also Béland, 1990; Béland & Favreau, 1991; Béland, Paradis, & Bois, 1993; Carter, Gerken, & Holland, 1998; Christman, 1994; Code & Ball, 1994; Den Ouden, 2002; Kohn, Melvold, & Smith, 1995; Nespoulous, Joannette, Béland, Caplan, & Lecours, 1984; Nespoulous, Joannette, Ska, Caplan, & Lecours, 1987; Nespoulous & Moreau, 1997, 1998; but see Favreau, Nespoulous, & Lecours, 1990; and for case studies, see Béland & Paradis, 1997; Kohn & Smith, 1994; Romani & Calabrese, 1998; Romani et al., 2002). While these studies all point to the relevance of the notions of markedness somewhere within speech production, they are limited by a lack of detailed information regarding the level at which these effects arise. This is because, in addition to their production deficits, many of the individuals in these studies suffered from comprehension deficits (e.g., nearly half of the individuals studied in Den Ouden (2002) or (sometimes subtle) deficits to articulatory processing (see Blumstein, 1998, for a review).

In fact, the differences of opinion regarding the organisation of the spoken production system not only concern the detailed content of phonological representations but also the level at which the

various aspects of phonological representation are specified. Some researchers posit an early specification of featural, syllabic, and prosodic information at the lexical level, others posit a later post-lexical or even articulatory specification of this information, and yet others propose that different aspects of phonological information are represented at different levels. Cognitive neuropsychological research provides the opportunity to use selective deficits affecting specific processes to develop a deeper understanding of the representational and processing distinctions respected by the phonological machinery. In doing so it may also contribute to what currently may well be the most controversial issue in linguistic theories of sound structure—the distinction between phonology and phonetics. The distinction between the categorical, discrete, and abstract descriptions of the phonology and the continuous, graded variables traditionally associated with phonetics (Hale & Reiss, 2000; Keating, 1988; Pierrehumbert, 1990) has recently been vigorously debated (e.g., Ohala, 1990; Pierrehumbert, Beckmann, & Ladd, 2000) and alternative positions put forward. In this context, the challenge for cognitive neuropsychological work (as it has been for theoretical linguistics) is to identify the level at which the phenomena of interest (e.g., errors) arise (Goldrick & Rapp, 2004). To date this has been difficult because, among other things, the representational types supporting phonological, phonetic, and articulatory processes are typically assumed to be similar along a number of dimensions.

As a consequence of the difficulties involved in attributing deficits to particular levels of representation, researchers have reached different conclusions regarding the level at which particular aspects of phonological structure are represented. For example, Béland, Caplan, and Nespoulous (1990) and Kohn and Smith (1994) came to different conclusions regarding the level at which syllabic structure is specified. Similarly, while Romani et al. (2002) claimed that features are specified during post-lexical processing, Kohn et al. (1995) claimed that (marked) features are specified at the lexical level.

In sum, the situation in 2004 is not unlike that faced by Ellis, who in 1985 was concerned with the relative paucity of research in this area. Future theoretical work must do more to contribute to a more precise understanding of the level/s at which featural, syllabic, and prosodic information is represented and processed in the course of spoken, word production (see Goldrick & Rapp, 2004). Another important issue concerns the phonological level/s at which *lexical* variables such as grammatical category, lexical frequency, and neighbourhood density are relevant. Some theories assume fairly restricted early representation of lexical variables while others posit a more widespread representation or influence of lexical factors at post-lexical and even articulatory levels. Finally, also important are questions of activation dynamics (similar to those raised earlier) regarding the extent to which processing is highly interactive or modular in this part of the spoken production system.

The relationship between spoken word production and comprehension

This question is still a holdover from the set of issues identified by Ellis (1985) and is a part of the far broader question concerning the relationship between perception and action in a variety of domains (e.g., nonlinguistic actions, written language, etc.). Within the domain of spoken word production, this question consists of a number of subquestions, such as: (a) Are common mechanisms (lexicons, buffer, etc.) used in comprehension and production? (b) Does the feedback connectivity in spoken production correspond to the feed-forward connectivity in comprehension? (c) How does monitoring of spoken word production operate and what is its relationship to comprehension? Although considerable work has been carried out on many of these topics (e.g., Dell et al., 1997b; Howard, 1995; Martin & Saffran, 2002; Nickels & Howard, 1995; Romani, 1992; Shallice, Rumati, & Zadini, 2000), we are far from having clear answers.

The challenge for cognitive neuropsychological work is to derive clear predictions that discriminate between the shared and independent systems views. The principal strategy thus far has been to document if production and comprehension deficits occur in association with one another or if they dissociate. The primary difficulty has been that, at least at a general level, dissociations and associations can be accommodated by both shared and independent systems views. Dissociations are accounted for by a shared systems view by assuming that, at least in one modality, the deficit affects access to the representations of interest. Associations are accounted for by an independent systems view as the accidental result of neural damage affecting multiple components. One possibility is that progress in developing a more detailed understanding of the phonological processes involved in production (see the previous section) will provide a more substantive basis from which to formulate hypotheses that will allow us to investigate and understand the relationship between comprehension and production. That is, as we understand production better, we will be in a stronger position to test whether or not the same representations and processes are involved in comprehension.

Speaking words in sentences: Grammatical and morphological processes

Research efforts on spoken word production and sentence production have proceeded fairly independently of one another. This has had the advantage that it has allowed us to establish some terra firma in the two domains, providing the theoretical and evidential scaffolding required to support interaction and integration of these domains. Given these advances, the general question now before us is: How are lexical selection, phonological encoding, and articulatory planning affected by sentential context?

There is evidence that lexical selection and encoding processes are affected by taking place within a sentential context or merely by occurring in the context of a string of words

(e.g., Caramazza & Hillis, 1989; McCarthy & Kartsounis, 2000; Nespoulous et al., 1988; Schwartz & Hodgson, 2002; Wilshire & McCarthy, 2002). For example, Schwartz and Hodgson asked MP to name the same set of pictures in two contexts. One was standard picture naming, with a single picture and a single response required (e.g., picture of cat → “A cat”). In the second context, two pictures were presented side by side, and MP was required to name them both in a single utterance (e.g., cat, ear → “A cat and an ear”). Her accuracy in the first context was relatively high (92%), but it was dramatically decreased in the second context (42%). Note that many of her errors were not simply reversals (e.g., “An ear and a cat”), but productions of the incorrect lexical item (e.g., “A pie and a fan”). These results indicate that lexical selection can be influenced by the spoken language context.

Given the role of morphology and grammatical features in sentential syntax, work in this area should be particularly helpful in shedding light on the various debates concerning the morphological and grammatical representation and processing of words that have been highlighted in previous sections. Furthermore, the temporal relationships between processes sensitive to the grammatical, morphological, and phonological aspects of words also require clarification. Contrasting spoken word production in contexts in which grammatical and morphological processes are most likely to be engaged with single word production will surely provide important insights into the spoken production system.

Activation dynamics: Competition, inhibition, decay, buffering

Although most theories characterise speech production as involving activation flow among various representational types, there is a striking lack of specificity regarding the means by which this activation is regulated and controlled. This is a crucial question, because competition among activated representations plays a significant role in speech production. During lexical selection, multiple semantic competitors are activated

(e.g., during the processing of “cat,” “dog,” and “rat” are also activated). When producing sequences of words or sounds, the representations of sounds and words to be produced or that have already been produced may all be simultaneously active (as shown by anticipation and perseveration errors). Therefore, a critical set of issues concerns the mechanisms that mediate this competition.

One relevant mechanism is the selection process—how is it that a single activated representation comes to dominate processing? One selection mechanism that has been proposed involves enhancement of the most active representation. In some theories, the most active unit’s activation is greatly increased at certain “selection” points. This activation advantage allows the selected unit to dominate processing. One way that this enhancement can be achieved is through an outside mechanism that simply adds activation to the “winning” unit (Dell, 1986, 1988; Dell et al., 1997b; Goldrick & Rapp, 2002; MacKay, 1987; Rapp & Goldrick, 2000). Another enhancement method is a competitive process by which active representations deactivate competitors to a degree that is proportional to their own activation strength. That is, the more active a representation, the more it can drive down (inhibit) the activation of its competitors (see Dell & O’Seaghdha, 1994, for a review). This is often implemented in language production theories using lateral connections among units of a similar representational type (e.g., Berg & Schade, 1992; Cutting & Ferreira, 1999; Harley, 1993; Meyer & Gordon, 1985; Schade & Berg, 1992; Stemmer, 1985). Note that a similar process occurs in attractor-based systems (e.g., Plaut & Shallice, 1993). Here, since different representations compete for realisation over a single set of units, the activation of one representation necessarily blocks the activation of another (see Page (2000), for further discussion of the relationship between lateral inhibition and attractors). Another selection-related mechanism involves “gating” activation flow—units are not allowed to pass on activation to other units until they meet some response criterion (e.g., a threshold of activation: Dell et al., 2004; Laine et al., 1998;

or a relative activation level that is sufficiently greater than competitors: Levelt et al., 1999; Roelofs, 1992).

While inhibition is an active process, intimately related to selection, other theories have adopted a more passive mechanism to drive down competitor activation. These theories posit that all activation levels constantly decay towards resting levels; units can only maintain activity if they receive outside input (Dell, 1986, 1988; Dell et al., 1997b; Harley, 1993; Martin et al., 1994). A number of studies have suggested that a pathological increase in decay can account for spoken production deficits (Dell et al., 1997b; Martin, 1996; Martin et al., 1994; Martin & Saffran, 1992; Schwartz & Brecher, 2000). One problem for this proposal is that other studies have argued that the patterns of performance attributed to excessive decay can be accounted for by other forms of damage (Foygel & Dell, 2000; Wright & Ahmad, 1997).

Thus, although many studies have invoked disruption to selection mechanisms to account for spoken production deficits, specific questions about these selection mechanisms (e.g., enhancement, inhibition, or decay) have not received much attention.

Another issue regarding activation dynamics is the role of buffering processes. Buffering comes into play when interacting processes function on different time scales. For example, in planning a sentence, a plan for a phrase might be activated and this phrase may need to be maintained active while each component lexical item is retrieved. Similarly, when a lexical item is retrieved, it may need to remain active to guide post-selection processing of its phonological components. A small number of case studies (see Shallice et al., 2000, for a review) have attributed production deficits to impairment to a phonological buffering process. Although these studies support the presence of such a buffer, considerable work remains to be done in specifying the precise nature of temporal ordering mechanisms (see below) and the structure of representations that are buffered. Furthermore, there are a number of reasons to think that there are buffers or buffering processes

operating at multiple levels in the system. That is, speech production behaviour requires that activation be maintained at various points in processing; existing theoretical and empirical studies have done little to resolve how this is accomplished.

Representing time

The precise orchestration of events over time is an essential aspect of producing spoken words. It is, therefore, imperative for the time dimension to be more fully integrated into our theories of spoken word production. Specifically, the temporal dimension is an essential component of mechanisms and representations involved in ordering (e.g., to distinguish “cat” and “tack,” segment order must be respected), timing (e.g., to correctly articulate voiced and voiceless stop consonants, the relative timing of consonant release and vocal fold vibration must be controlled), and duration (e.g., to signal obstruent voicing/devoicing in word-final position, the length of the previous vowel must be controlled). Fortunately, there is both theoretical and computational work that can contribute to cognitive neuropsychological efforts to bring patterns of impaired performance to bear on this important aspect of spoken production.

Recent theoretical work in phonology and phonetics directly tackles the problem of incorporating the temporal dimension into the representational formalism. This research includes proposals such as those of Browman and Goldstein (1992) in articulatory or gestural phonology. In their approach, the temporal dimension forms a part of categorical phonological representations themselves, providing an interface with the more graded, continuous representations of phonetics. As can be seen in Figure 6, in this theoretical framework the duration of gestures is specified and (although not depicted) the temporal coordination of these gestures is specified as well. Introducing this temporal information into phonological representations has extended the descriptive and explanatory power of linguistic theories (Browman & Goldstein, 1992; for

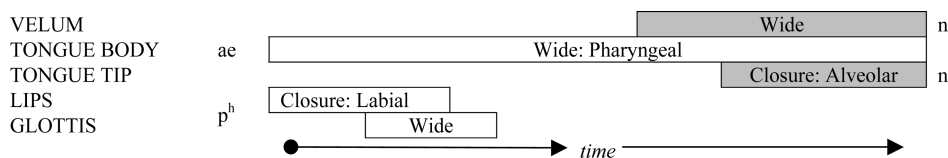


Figure 6. Schematic articulatory phonological representation (gestural score) of “pan.” Articulators are shown on the left-hand side. Letters on the left and the right show the association between articulatory gestures and elements in the segmental transcriptions. For each articulator, the bar represents the time during which the articulator is active. Labels within the bar refer to the degree of constriction; for some articulators, location is specified following a colon. Wide indicates that the degree of constriction is low, while closure indicates a high degree of constriction.

recent applications, see Davidson, 2004; Gafos, 2002; Hall, 2003).

Computational work on the questions of time and serial production has developed in a number of directions. The shared objective of the various approaches is to understand how information is represented and processed to allow for the production of learned, temporally ordered sequences such as spoken words (see Lashley, 1951, for a seminal discussion of this issue).

One line of work has focused on developing more sophisticated versions of older chaining mechanisms used for encoding order. In a chain-based representation, the production of one element (e.g., a phoneme) triggers the production of the following element in the sequence, by virtue of being linked to it. Recurrent network simulations represent recent work along these general lines. In these networks, learning involves encoding the relationship between a distributed representation of an element (e.g., a set of phonemic features) and a distributed representation of the previous element and/or learning context (Dell, Juliano, & Govindjee, 1993; Elman, 1990; Jordan, 1986). Once learning has taken place, the activation of an element provides the context for the activation of the subsequent element in the sequence, and this process continues successively until the end of the sequence. These networks can reproduce a number of salient findings that have been reported for slips of the tongue produced by neurologically intact individuals, including such things as the preservation of phonotactic regularity and consonant/vowel status in substitutions, etc. (see Anderson, Milostan, &

Cottrell, 1998; Dell et al., 1993, for discussions of the strengths and limitations of this approach). These approaches have not yet, however, been applied to spoken word production in aphasia.

Another direction taken to understanding the ordering question has been the computational instantiation of slot and filler mechanisms. This work contrasts with the chaining approach in assuming a fundamental distinction between content and structure. Information regarding ordering is represented in a structural frame, while the elements to be ordered are independently represented. For example, in producing the form of the word “creed”/k r i d/, both a frame specifying a monosyllabic word with a complex onset, nucleus, and simple coda and the phonological content (the component phonemes) of the word are retrieved from memory. Subsequently, the phonemes are linked to their respective syllabic positions via some “slot filling” process. Errors may arise at various points; for example, in the retrieval of the frame or the content, in the course of slot filling, or in readout from the filled slots (e.g., Dell, 1986, 1988; Dell, Burger, & Svec, 1997a; Hartsuiker, 2001; Levelt, 1989; Levelt et al., 1999; MacKay, 1972, 1987; Meijer, 1994; Shattuck-Hufnagel, 1979, 1992; Stemmerger, 1985). (Note that these approaches use different methods for binding frame and content; see Dell, Ferreira, & Bock, 1999; Levelt et al., 1999.) This approach has been successfully applied to slips of the tongue and, to a more limited extent, to data from aphasia as well (e.g., Pate, Saffran, & Martin, 1987; Schwartz, Saffran, Bloch, & Dell, 1994; Wilshire, 2002;

Wilshire & McCarthy, 1996). The slot and filler approach has been able to handle certain of the phenomena not well accommodated by recurrent networks, but faces its own set of challenges (for a review, see Dell et al., 1997a).

Finally, there are a number of computational approaches in which order, timing, and duration are represented through the association of the elements to be ordered (e.g., phonemes) with timing units that have intrinsic temporal characteristics (e.g., oscillators). It is this direct and explicit incorporation of timing elements into the production process that distinguishes this approach from the previous two. In describing the basic logic of the approach, Brown, Preece, and Hulme (2000) use a clock analogy such that the hour, minute, and second hands of a clock are analogous to slow, intermediate, and fast oscillators. During learning, the clock starts and, as time passes, each phoneme is associated with (linked to) a particular configuration of the hands. Then, at the time of retrieval, the clock is started and its associated elements are produced as time unfolds (for specific applications to speech production, see Harris, 2002; Hartley & Houghton, 1996; Vousden, Brown, & Harley, 2000). This approach has a number of advantages over the previous ones, although it too suffers from its own set of limitations.

In sum, to date questions regarding the representation and processing of temporal ordering and duration have scarcely been addressed in cognitive neuropsychological work on spoken word production. However, advances in theoretical linguistics and computational theories of speech production provide a number of frameworks within which to pursue this complex, yet critical, dimension of spoken word production.

Conclusions

The last 20 years have been a testament to the vitality and productiveness of the cognitive neuropsychological approach in the domain of spoken word production. We have seen clear progress made on a number of macro and micro structural issues. This work has revealed a

dynamic, yet internally structured system that is instantiated in the brain in a manner that allows for the fairly selective damage to individual components of meaning, form, as well as grammatical and lexical properties. The next 20 years will require that we build on the architectural and representational foundations of the preceding years in order to develop far more detailed and computationally explicit theories of spoken language processing. Such theories will help us to understand the real-time transitions from categorical to continuous representations that allow us to fluently produce words both in isolation and in sentences. It is difficult to imagine that computer simulation will not play an important role in the theory testing and development that will be required to make progress on these questions. Furthermore, it is essential that we continue to actively work for the broader integration of cognitive neuropsychological evidence into theory development in cognitive science, psychology, linguistics, and neuroscience.

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