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## Contrasting effects of phonological priming in aphasic word production

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### Abstract

Two fluent aphasics, IG and GL, performed a phonological priming task in which they repeated an auditory prime then named a target picture. The two patients both had selective deficits in word production: they were at or near ceiling on lexical comprehension tasks, but were significantly impaired in picture naming. IG's naming errors included both semantic and phonemic paraphasias, as well as failures to respond, whereas GL's errors were mainly phonemic and formal paraphasias. The two patients responded very differently to phonological priming: IG's naming was facilitated (both accuracy and speed) only by begin-related primes (e.g. *ferry-feather*), whereas GL benefited significantly only from end-related primes (e.g. *brother-feather*), showing no more than a facilitatory trend with begin-related primes. We interpret these results within a two-stage model of word production, in which begin-related and end-related primes are said to operate at different stages. We then discuss implications for models of normal and aphasic word production in general and particularly with respect to sequential aspects of the phonological encoding process.

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Most current models identify at least two major processes or stages to word production—lexical selection and phonological encoding (Bock & Levelt, 1994; Butterworth, 1989; Caramazza, 1997; Dell, 1986, 1988; Harley, 1984; Levelt, 1989; Levelt, Roelofs,

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& Meyer, 1999; MacKay, 1987; Roelofs, 1992, 1997; Stemmer, 1985).<sup>1</sup> During lexical selection, the desired concept is converted into a lexical representation. This representation is specified as to its semantic and possibly also its syntactic properties, but not its phonological properties. During phonological encoding, a complete phonological plan for the word is generated. This second, phonological encoding stage is variously conceptualised. Many symbolic models incorporate a lexical store that contains phonologically specified representations of all known words, sometimes called the “phonological output lexicon”. A phonological representation for the word is retrieved from this lexicon, and may then undergo further processing to be transformed into a complete, fully ordered phonological plan (see e.g. Butterworth, 1989; Garrett, 1975; Shattuck-Hufnagel, 1979, 1983). In contrast, in many spreading activation models, there is a single, universal set of phoneme representations, and information about a word’s form is embodied in the connections between the word’s lexical representation and those of each of its phonemes.<sup>2</sup> During phonological encoding, activation passes along these connections to activate the correct set of phonemes. Like symbolic models, this information may then undergo further processing (see for example, Caramazza, 1997; Dell, 1986, 1988; Harley, 1984; Levelt, Roelofs, & Meyer, 1999; MacKay, 1987; Roelofs, 1997; Stemmer, 1985, 1990). Further, in some of these models, activation within phonological representations “feeds back” to lexical representations, thereby directly influencing lexical-level processes (e.g. Dell, 1986, 1988; Dell & O’Seaghdha, 1991, 1992; Harley, 1984; Stemmer, 1985; for recent discussions on this issue, see Dell, Schwartz, Martin, Saffran & Gagnon, 2000; Levelt et al., 1999; Rumel & Caramazza, 2000; Rumel, Caramazza, Shelton, & Chialant, 2000).

A central issue surrounding phonological encoding concerns the phoneme ordering process. In some models, the retrieval of lexically stored phonological information is not order-sensitive; information about all the phonemes in the word becomes available at the same time (Dell, 1986, 1988; Levelt et al., 1999; O’Seaghdha & Marin, 2000; Roelofs, 1997; Shattuck-Hufnagel, 1979, 1983, 1987, 1992; Stemmer, 1985). Phonemes are ordered on the basis of number labels (e.g. Levelt et al., 1999; Roelofs, 1997), or syllable position coding (e.g. Dell, 1986; MacKay, 1987; Shattuck-Hufnagel, 1979, 1983, 1987, 1992). In these models, subsequent, postlexical phonological processes may operate sequentially, but the retrieval process itself is strictly parallel (see O’Seaghdha & Marin, 2000; Roelofs, 1997; for examples that explicitly incorporate this parallel-then-sequential feature). In other models, phonological encoding is sequential right from the outset. For example, in many spreading activation models, the representations of the word’s early phonemes initially receive more activation than those of later ones (Dell, Juliano, & Govindjee, 1993; Hartley & Houghton, 1996; Houghton, 1990; Meyer, 1991; Sevald & Dell, 1994; Vousden, Brown, & Harley, 2000). This activation differential may be very

<sup>1</sup> Distributed models such as Plaut and Shallice (1993) contain no explicit lexical level of representation. Nevertheless, these models incorporate a set of “hidden units” that are likely to behave in a similar way to lexical representations in a fully trained model (see Lambon-Ralph et al., 2000 for further discussion).

<sup>2</sup> In some models, there may be intermediate layers of representations between the lexical and the phonological layers (for example, morphological nodes: Levelt et al., 1999; or syllable nodes: Dell, 1986; MacKay, 1987), or there may be two layers of lexical representations that differ with respect to their connections to syntactic, semantic and other related information (e.g. Levelt et al., 1999).

pronounced, with phonemes receiving little activation until their “turn” comes to be retrieved (e.g. Dell et al., 1993; Hartley & Houghton, 1996; Meyer, 1991), or may be relatively shallow (e.g. Houghton, 1990; Sevald & Dell, 1994). There may also be subsequent segment-frame assignment processes (see especially Sevald & Dell, 1994), but these do not carry the entire burden of phoneme sequencing.

Investigating the phoneme ordering process is by no means easy. One approach is to examine spontaneous errors for asymmetries across word positions. For example, it has been reported that the phonological slips of the tongue produced by normal speakers tend to involve word onsets more often than non-onset phonemes (MacKay, 1970; Shattuck-Hufnagel, 1987; Wilshire, 1998), and conversely, that in the phonological errors of aphasic individuals, word onsets are preferentially spared (Kohn & Smith, 1994, 1995; Schwartz, Wilshire, Gagnon, & Polansky, 2004; Wilshire, 1998, 2002). However, it could be argued that these descriptive analyses provide only indirect evidence about the phoneme ordering process. An alternative approach is to systematically manipulate phoneme serial position in priming paradigms (e.g. Collins & Ellis, 1992; Meyer & Schriefers, 1991). Here we can vary the position of the phonemes shared between similar sounding words and examine the effect on performance. In the present study, we examine the effect of various types of form-related primes on the word production of two language-impaired individuals. We interpret our data within a simple two-stage spreading activation framework based on that proposed by Dell and colleagues (see esp. Dell & O’Seaghdha, 1991; Dell, Schwartz, Saffran, Martin, & Gagnon, 1997; Foygel & Dell, 2000).

The simplest version of the model proposed by Dell and colleagues (henceforth the “Dell model”) comprises a network consisting of three layers of localist nodes—phonological, lexical and semantic. Related nodes at corresponding levels are interconnected (see Fig. 1). During word production, activation spreads down the network from the semantic to the lexical nodes (the lexical selection stage), then from lexical to the phonological nodes (the phonological encoding stage). As each node becomes activated, it then transmits activation to other interconnected nodes at both lower levels (“feed-forward”) and higher levels (“feedback”). At each level, the most highly activated node is “selected” after a specified period of time and then receives an additional activation boost. This model has the advantage that it is computer implemented and therefore is highly explicit regarding its predictions. Also, since it was originally developed to capture error

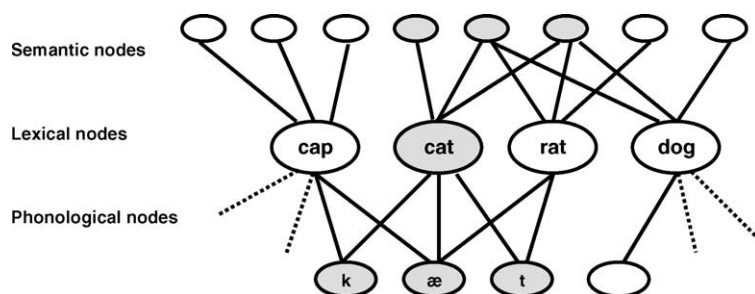


Fig. 1. An example lexical network based on the simple Dell model (Dell & O’Seaghdha, 1991; Dell et al., 1997; Foygel & Dell, 2000). The figure shows that part of the lexical network associated with the representation of the word “cat”.

phenomena, it lends itself easily to the study of impaired aphasic speech (we consider the issue of model choice at the end of the paper).

### 1. The phonological priming task

In the phonological priming task, a word to be produced is preceded by, or accompanied by, a phonologically related prime word. Using this task, we can manipulate the degree and nature of the phonological overlap between prime and target—for example, compare the effects of begin-related primes (e.g. *spiral-spider*) and end-related primes (e.g. *ladder-spider*). Many studies report facilitatory effects with phonologically related primes: naming latencies have been found to be reduced (compared to a control, unrelated condition) when the target to be named follows a phonologically related prime (Bajo & Cañas, 1989; Bowles & Poon, 1985; Collins & Ellis, 1992; Lupker & Williams, 1989; McEvoy, 1988) or is accompanied by a phonologically related auditory word (see also Costa & Sebastian-Gallés, 1998; Damian & Martin, 1999; Meyer & Schriefers, 1991; Meyer & van der Meulen, 2000; Peterson & Savoy, 1998; Schriefers Meyer, & Levelt, 1990). This facilitatory effect has been found even when there is little or no overlap in input processing between prime and target, which suggests it is not simply due to facilitation during word recognition. The effect appears to be particularly strong when the target task is picture naming, regardless of the nature of the prime (Bajo & Cañas, 1989; Lupker & Williams, 1989). Nevertheless, not all phonological priming studies report facilitation. Inhibitory effects have also been obtained, particularly when the target words used are very high in frequency, or are presented in close succession (Grainger, 1990; Lupker & Colombo, 1994; O’Seaghdha, Dell, Peterson, & Juliano, 1992; O’Seaghdha & Marin, 2000; Radeau, Morais, & Segui, 1995), or when the same stimuli serve as both primes and targets (Sullivan & Riffel, 1999).

Two mechanisms have been proposed to account for phonological priming in word production, both of which can be understood within a generic, two-stage framework. The first operates at the phonological encoding stage. Within models that incorporate a single common set of phonological representations, processing of the prime activates the representations of phonemes that are later required for target production. These remain partially active at the time the target is presented; so phonological encoding of the target can be accomplished more quickly (e.g. Meyer & Schriefers, 1991; Schriefers et al., 1990). The second proposed mechanism operates at the lexical selection stage: the prime increases activation in the representation(s) corresponding to the target word, so the process of lexical selection can be accomplished more quickly (e.g. Collins & Ellis, 1992; Lupker & Williams, 1989; O’Seaghdha & Marin, 2000). This lexical selection mechanism also generally leads to facilitation, although according to some accounts, the mutual activation between prime and target can sometimes lead to inhibition: if the target reaches full activation quickly, it may reactivate the prime to such an extent that the prime’s phonemes then compete for selection (O’Seaghdha et al., 1992; O’Seaghdha & Marin, 2000; Peterson, O’Seaghdha, & Dell, 1996).

In the context of the Dell model, the processing of a phonologically related prime could potentially facilitate target production in two ways: either (a) by generating activation in

some of the phonological nodes later required for the target word (the “phonological” mechanism); or (b) by heightening the activation level of the target’s lexical node itself (the “lexical” mechanism). The latter, lexically mediated effect could potentially occur as a result of feedback activation from the prime word’s phoneme nodes to the phonologically related target lexical node (although if the prime is auditorily presented, some such facilitation could also occur during actual prime recognition). One or both mechanisms could contribute to the previously reported facilitatory phonological priming effects.

## 2. Serial position effects in the phonological priming task

In the Dell model described above, phonological encoding proceeds in parallel across the word. Phoneme order is determined by the position information associated with the phonological nodes themselves (the nodes are marked as to whether they represent onset, vowel or coda phonemes). Therefore, according to this model, the production of a phonologically related prime word will have similar effects on subsequent encoding of the target word, regardless of the position of the phonemes shared between prime and target. However, it has recently been proposed that the phonemes of a word may be activated not in parallel, but rather in sequential order (e.g. Dell et al., 1993; Houghton, 1990; Sevald & Dell, 1994; Vousden et al., 2000). If this were the case, then we would expect different effects for begin-related and end-related primes. When the prime is begin-related, the critical phonemes in the prime word would be activated early during prime production. Therefore, in an interactive model such as the Dell model, these phonemes would have more opportunity to feed activation back to the target lexical node, thereby increasing the chances of lexically based target facilitation. On the other hand, for end-related primes, the critical shared phonemes would be activated relatively late, so these phonemes would have less opportunity to feed activation back to lexical representations, and would be less effective at facilitating target lexical selection. Rather, the effect of these primes would be largely confined to the phonological encoding stage. In conclusion then, while both begin-related and end-related primes would have the potential to facilitate encoding of the target word’s shared phonemes, the former would have a greater opportunity to influence lexical-level processes (for a similar argument, see Sevald & Dell, 1994).

There is currently little evidence to support these predictions. Few studies of word production in normals have incorporated a direct comparison between begin-related and end-related primes, and those that do have failed to obtain significant differences in their overall effectiveness, either in tasks giving rise to facilitation (Collins & Ellis, 1992; Meyer & van der Meulen, 2000; O’Seaghdha & Marin, 2000 (low frequency targets)); or in tasks yielding inhibition (O’Seaghdha & Marin, 2000 (high frequency targets); Sullivan & Riffel, 1999). Nevertheless, there is a slight trend towards stronger facilitation and/or weaker inhibition with end-related primes, which suggests there may be some small differences that are difficult to detect under normal conditions (facilitation: Collins & Ellis, 1992; Meyer & van der Meulen, 2000; O’Seaghdha & Marin, 2000 (low frequency targets); inhibition: Sullivan & Riffel, 1999). Also, the time course of operation may be different for the two types of primes. Cross-modal auditory word-picture interference

studies suggest that the critical period of effectiveness for end-related primes may be later and more limited than that for begin-related primes (Meyer & Schriefers, 1991). This effect may originate entirely at the phonological encoding stage—from differences in the time at which beginning and later phonemes become activated—or alternatively, it may indicate a difference in the actual stage at which each of the primes operates.

However, there are reasons to believe that studies of naming latencies in normal speakers may not be the best way to examine these kinds of word position asymmetries. Naming latency effects in normals are likely to reflect the combined activity of a number of quite different processes, including not only word production, but also conceptual processing, articulatory programming and possibly also strategic processes. Indeed, the processes that take place during word production itself might be quite rapid, and might therefore contribute little to overall naming latencies. If the reductions in processing time are positive but small in for both begin-related and end-related primes, differences between the two prime types might be difficult to detect in normal latencies. In the current study, we compare the effects of begin-related and end-related primes on target word production using a different dependent variable—the accuracy and speed of word production in language-impaired individuals.

### 3. Phonological priming in aphasia

The rationale behind studies of priming in normal individuals is as follows: if a particular type of prime reduces production latencies, then the processing of the prime must have activated representations that are also required for target production. In this paper, we examine priming in patients with *impaired* word production. The reasoning is that, if the processing of a prime word activates some of the representations required for target production, then the use of this type of prime may also improve *accuracy*—depending, of course, on the nature of the representations activated and the exact locus of the patient's impairment. The use of aphasic individuals may have certain advantages. Unlike studies with normals, in which the locus of priming effects must be inferred indirectly, priming effects obtained with aphasics may be more readily localisable to a specific stage of processing. In a patient who has an independently documented impairment involving a particular processing stage, any gross effects of priming on performance, particularly on overall accuracy, are likely to be attributable to processes operating at the impaired stage. Also, unlike the fine-grained latency effects that are obtained with normal subjects, any gross changes in aphasic naming accuracy are less likely to be attributable to purely strategic factors such as subject expectation. And finally, we may be able to investigate processes that are accomplished very automatically and/or rapidly by normals, and are therefore difficult to isolate using broad techniques such as priming.

Spoken word production is a skill that can become quite selectively impaired in aphasia. There are numerous reports of individuals who have excellent word comprehension skills (as measured in stringent word-to-picture matching tests), and who produce fluent, well-articulated and grammatically well-formed speech, but who appear to have difficulty producing particular words (Badecker, Miozzo, & Zanuttini, 1995;



Gainotti, Silveri, Villa, & Miceli, 1986; Henaff Gonon, Bruckert, & Michel, 1989; Howard, 1995; Kay & Ellis, 1987; Lambon-Ralph, Sage, & Roberts, 2000; Raymer, Foundas, Maher, & Greenwald, 1997). These patients' speech may be punctuated with word-finding pauses, circumlocutory descriptions of unavailable words, and often outright phonological and/or semantic errors. Such individuals tend to have particular difficulty on more constrained tasks such as picture naming, where they may produce phonological and/or semantic errors, or fail to attempt the item altogether. They are generally well aware of their errors, and often provide a detailed semantic description of the unavailable word. Many early reports of these patients interpreted their deficits within a simple functional architecture framework, which incorporates a general cognitive/semantic system, a phonological output lexicon that stores the phonological representations for all known words, and a phonological "response buffer" or "output buffer" that temporarily holds a phonological plan for an utterance prior to its articulation (see e.g. Caramazza, Miceli & Villa, 1986; Morton & Patterson, 1980; Patterson & Shewell, 1987; see also Kay, Lesser and Coltheart, 1992). In terms of this framework, the patients are able to generate the correct semantic representation of the desired word, but are unable to retrieve its full entry from the phonological output lexicon (see, e.g. Kay & Ellis, 1987; Hirsh, 1992; Caramazza & Hillis, 1990; Franklin, Howard, & Patterson, 1995). Some, whose errors are primarily phonological, and who also have great difficulty on tasks where the phonological output lexicon can be by-passed—such as reading and repetition—may be characterised as having a deficit involving the phonological output buffer (see e.g. Bub, Black, Howell & Kertesz, 1987; Kohn, 1989; for recent discussions of the distinction between "lexical" and "postlexical" phonological processing, see Goldrick, Rapp, & Smolensky, 1999; Schwartz et al., 2004; Wilshire, 2002).

In terms of the more recent, two-stage view of word production, these selective deficits in word production could in principle indicate a problem at either or both of the two stages. One relatively universal prediction is that failures at the lexical selection stage will tend to elicit semantic errors rather than phonological errors, whereas failures at the phonological encoding stage will tend to elicit phonological errors. In terms of the Dell model, the argument runs as follows: if the activation transmitted to the lexical level is weak or noisy (that is, there is a problem at the lexical select in stage), the target lexical node may not become sufficiently activated to be selected over its competitors—and the strongest competitors are likely to be semantically related words that receive partial activation by virtue of their shared features with the target. In contrast, if activation transmitted to the phonological level is weak or noisy, it may be insufficient to enable some of all of the word's phonemes to be activated above their competitors—and the result will be a phonological error. In the literature, there are good examples of both predicted error patterns. Some patients produce many semantic errors, but few phonological errors (e.g. Caramazza & Hillis, 1990; Rapp & Goldrick, 2000 (PW); Cuetos, Aguado, & Caramazza, 2000). These patients' good comprehension rules out a more general semantic disorder; nevertheless, their high rate of semantic errors suggests a deficit in lexical selection. Other individuals make few semantic errors, but many phonological errors, suggesting a deficit in phonological encoding (e.g. Caplan, Vanier, & Baker, 1986; Caramazza, Papagno, & Rumel, 2000; Rapp & Goldrick, 2000 (CSS); Kohn, 1989; Pate, Saffran, & Martin, 1987; Wilshire & McCarthy, 1996; Shallice, Rumati, & Zadini, 2000; Wilshire, 2002).

Most of what is known about aphasic word production deficits comes from qualitative studies of aphasic errors. Techniques like phonological priming have rarely been used. Nevertheless, one commonly used task that shares many similarities with priming is *phonemic cueing*. Here, the aphasic person is provided with one or more phonemes of a word they cannot retrieve (e.g. *spider* → /sp-/). The most common type of cue given is the initial phoneme cue, the first one or two phonemes of the word. Many patients show facilitation with such cues (see, e.g. Best, Herbert, Hickin, Osborne & Howard, 2002; Graham, Patterson, & Hodges, 1995; Howard & Orchard-Lisle, 1984; Lambon-Ralph, Cipolotti, & Patterson, 1999; Lambon-Ralph et al., 2000; Li & Canter, 1987; Li & Williams, 1990, 1991; Pease & Goodglass, 1978; Podraza & Darley, 1977; Stimley & Knoll, 1991; see also Elman, Klatzky, Dronkers, & Wertz, 1992, where phonemic cues were presented prior to the target picture). Facilitatory effects have also been reported with rhyme cues (e.g. “at” for “cat”), although the effect is often weaker when measured across groups of patients (Best et al., 2002; Howard, Patterson, Franklin, Orchard-Lisle, & Morton, 1985).

Interestingly, phonemic cueing is not successful with all aphasics (Howard, 1995; Li, & Canter, 1987; Podraza & Darley, 1977). Most case studies reporting positive effects have been based on the use of initial phoneme cues with patients who make significant numbers of semantic errors and/or failures to respond, but who produce few actual phonological errors—that is, those whose primary deficits appear to involve the lexical selection stage (see for example, Graham et al., 1995; Howard & Orchard-Lisle, 1984; Lambon-Ralph et al., 1999, 2000). Indeed, Croot, Patterson, and Hodges (1999) compared two patients, and obtained facilitatory initial cueing effects in only one: Patient RB, whose errors in naming were mainly omissions and circumlocutions (suggesting a deficit in lexical selection), responded positively to phonemic cues, but CB, who produced many phonological errors, did not. Also consistent with this is the finding that, in group studies, semantic errors and circumlocutions are reduced following phonemic cues, but phonological errors remain at the same level or increase (Li & Williams, 1991; Stimley & Knoll, 1991). All these observations suggest that the effects of word-initial phonemic cueing may be largely lexically mediated; these cues seem to have little effect at the phonological encoding stage, perhaps because patients with phonological encoding deficits usually have more difficulty with word endings than word beginnings (Kohn & Smith, 1994, 1995; Schwartz et al., 2004; Wilshire, 1998, 2002), and these do not benefit at all from the initial phoneme cue.

Nevertheless, these differences in the effectiveness of phonemic cueing on lexical selection and phonological encoding impairments respectively constitute only a single dissociation, and as such may have alternative explanations. For example, the hypothetical “lexical selection” patients may simply have more severe impairments. A stronger theoretical argument could be made if we were able to establish another manipulation that had the *converse* effect—and this may be possible if we compare the effect of begin-related and end-related primes. If begin-related primes are more capable of influencing the lexical selection stage, then they may be more effective at facilitating naming in patients with lexical selection deficits than end-related primes. No such difference should be observed in patients with phonological encoding deficits.

In the experiments reported below, two aphasic individuals had to repeat a prime word, then name a target picture. The paradigm, which is based on Collins and Ellis (1992),



incorporates those features that most commonly elicit facilitation in normals—that is, long prime-target asynchronies, target words of medium to low frequency and different modalities of presentation for prime and target. Indeed, Collins and Ellis (1992) obtained significant facilitation with both begin-related and end-related primes. The two cases reported, IG and GL, both had a relatively selective impairment in word production; however, their errors in naming suggested a difference in the involvement of the lexical selection and phonological encoding stages respectively. We show that the two individuals differ in their relative sensitivity to begin-related and end-related primes, as would be predicted according to a sequential model of phonological encoding. Following detailed case descriptions of each patient, two experiments are reported. Experiment 1 explores the effect of different types of phonological primes. Experiment 2 then examines priming in more detail using each individual's most effective prime type.

#### 4. General information about participants

The two patients reported here, IG and GL, were tested as part of a larger study that included seven fluent aphasics, all of whom produced a significant proportion of phonological errors in naming. All seven were given a priming task similar to that described in Experiment 1; IG and GL were the only ones to show significant changes in naming accuracy as a result of the priming manipulations.

##### 4.1. Case description: Patient IG

IG, a retired engineer, suffered an ischaemic CVA following coronary bypass surgery in 1988, at age 69. A CT scan revealed an area of hypodensity in the middle and superior temporal gyri of the left hemisphere. When tested in 1991, his speech was described as fluent, but with word-finding pauses and some semantic and phonological errors. On the Boston Diagnostic Aphasia Examination (BDAE: Goodglass & Kaplan, 1983), IG's diagnosis was mild Anomic Aphasia. His scores on tests of single word comprehension were at normal or near-normal levels. However, naming was significantly impaired. On the Boston Naming Test (Goodglass & Kaplan, 1983), he correctly named only 53% of the targets on the first attempt. Aspects of IG's language performance have been described elsewhere (see, e.g. Dell et al., 1997; Foygel & Dell, 2000; Wilshire, 2002; Wilshire & McCarthy, 1996). Testing for the present study began in June 1997, nine years after IG's stroke, at age 78. At this time, he presented with fluent, informative speech, but still exhibited some word-finding difficulties and made occasional phonemic and semantic errors. As shown in Table 1, IG's single word comprehension was again found to be well-preserved: he performed well on word-picture matching and synonym matching tests, and could discriminate phonologically similar auditory words. He made several errors on an unpublished auditory word-picture matching test featuring phonologically related distractors (e.g. *cone-comb-coat*), but not enough to suggest a significant impairment in input phonological processing. Finally, IG was found to have a digit span of four.

IG performed three word production tests: (a) the Length and Frequency Naming Test, an 180-item picture naming test that contains equal numbers of monosyllabic, bisyllabic

Table 1

Patients IG and GL: proportion correct on tests of auditory comprehension and single word production

Test	IG	GL	Controls mean (SD) <sup>a</sup>
PALPA <sup>b</sup> real word minimal pair discrimination	0.94	0.74	–
Word-picture matching with phonological distractors (unpublished)	0.88	0.92	–
Philadelphia comprehension battery (Saffran et al., 1988):			
Lexical comprehension—within category word-picture matching	0.94	1.00	0.99 (.02)
Lexical comprehension—between category word-picture matching	0.96	1.00	0.99 (.01)
items with visual-perceptual distractors	1.00	1.00	–
items with phonological distractors	0.92	1.00	–
Synonymy judgement	0.97	1.00	0.97 (.05)
Word production: Task Effects Test (unpublished)			
Naming	0.63	0.45	–
Reading	0.96	0.70	–
Repetition	0.92	0.83	–

<sup>a</sup> Data from 23 control subjects reported in Breedin and Saffran (1999).<sup>b</sup> PALPA: Kay et al. (1992).

and polysyllabic items in each of three frequency groups; (b) the Task Effects Test, a test in which the same set of 120 words had to be produced in a picture naming, reading and a repetition task; and (c) a word/nonword repetition task, based on 20 bisyllabic words and 20 nonwords matched for phonemic length and phonological complexity (for further details of tests, see Wilshire, 2002). In the Length and Frequency naming test, IG correctly named 70% of monosyllables, 59% of bisyllables and 53% of polysyllables; this effect of length just failed to reach significance in a logistic regression analysis for length and frequency (parameter estimate for length: Wald  $\chi^2 = 3.53$ ,  $P = 0.06$ ). His scores on the high, medium and low frequency words were 68, 64 and 49% respectively; this frequency effect was significant (parameter estimate for frequency: Wald  $\chi^2 = 5.02$ ,  $P < 0.05$ ). However, Table 1 shows that, on the Task Effects test, IG performed at a much higher level on reading and repetition tasks than on picture naming. On these tasks, he produced only a small number of phonological errors and/or failures to respond. Finally, in the word/nonword repetition task, IG showed significant lexicality effects: he correctly repeated 17 of the 20 real words, but only 10 of the 20 nonwords.

Table 2 gives a breakdown of IG's first responses to pictures on the two naming tasks described above. IG produced *semantic paraphasias* (e.g. *crab* → “oyster”; *plug* → “socket”; *button* → “needle”; *scale* → “weight”) as well as *phonemic paraphasias* (phonologically related nonwords, e.g. *seesaw* → /sɪpsəl/; *dominoes* → /bægomæn/; *windmill* → /wɪnfɪl/). There were also a number of *formal paraphasias* (phonologically related real words, e.g. *camel* → “camera”) and mixed errors (e.g. *kite* → “skate”; *whale* → “seal”). “Other” errors consisted mainly of neologisms (e.g. *furniture* → /sɛsəriz/) or fragments. Overall, IG successfully self-corrected 22% of all his errors.

IG's phonological errors (that is, phonemic and formal paraphasias considered together) did not exhibit strong serial position effects. Percentages of phonemes correctly produced across Wing and Baddeley's (1980) five normalised word positions were 74, 70, 67, 68 and 67% for the five successive positions, respectively (for details of how phonemes

Table 2

Error breakdowns for IG and GL on standard picture naming tests (see text for tests used)

Error type	Proportion of responses	
	IG	GL
Correct	0.61	0.39
Phonemic paraphasia (phonologically related nonword) <sup>a</sup>	0.08	0.27
Formal paraphasia (phonologically related real word) <sup>a</sup>	0.03	0.13
Semantic paraphasia (semantically related word) <sup>b</sup>	0.08	0.04
Mixed error (semantically + phonologically related word) <sup>a</sup>	0.04	0.01
Omission (no attempt at the target)	0.08	0.03
Other	0.06	0.13

<sup>a</sup> A response was considered phonologically related if it had the correct first or last phoneme or two other phonemes in the correct position, or at least 30% correct phonemes in any position.

<sup>b</sup> All errors in this category were genuine semantic paraphasias; these highly selected, carefully piloted pictures did not elicit any appropriate non-target names (e.g. *couch* → *sofa*) from either patient.

are assigned to the five positions, see Wing & Baddeley, 1980; Miller & Ellis, 1987). While there was a trend towards higher accuracy on word beginnings than word endings, this did not reach significance: on a repeated measures logistic regression analysis for position on accuracy, there was no significant overall effect of word position (empirical standard error estimate for position: Wald  $\chi^2 = 0.54$ ,  $P = 0.46$ ).

#### 4.1.1. Summary and comment

IG suffers from a selective impairment in word production: his single word comprehension is well-preserved, even on stringent tests; his speech is fluent and well-articulated, but shows evidence of word-finding difficulties (pauses, and some outright errors); and he is markedly impaired on more constrained word finding tasks such as picture naming. On the latter, he exhibits strong frequency effects and produces a mix of both semantic and phonological errors. In terms of classical, functional architecture models, IG would be described as having an intact cognitive/semantic system, but an impairment accessing representations in the phonological output lexicon. In terms of a two-stage framework, his error mix would suggest some involvement of both the major stages: the phonological errors suggest a mild impairment affecting the phonological encoding stage, and the semantic and mixed errors suggest impairment at the stage of lexical selection.

#### 4.2. Case description: patient GL

GL, a mother and foster mother, suffered a haemorrhagic CVA following surgery for removal of a left intraventricular meningioma in October, 1992. This resulted in a pronounced aphasia, and a marked right hemiparesis. A CT scan revealed a large infarct encompassing the left posterior thalamus, and large cortical and subcortical regions of the left parietal lobe. On initial speech-language examination, GL's speech was described as "hesitant with many neologisms and paraphasias. Occasional intact sentences are fluent". Her comprehension was "inconsistent". This description indicates

a moderate to severe Wernicke's aphasia. When re-tested in July 1993, her speech was described as fluent, but with word-finding pauses, phonemic errors and occasional semantic errors. Also, despite its fluency, it had a slightly slowed, deliberate quality. On the BDAE, GL's diagnosis at this time was moderate conduction aphasia. Her test performance revealed good single-word comprehension, moderately impaired repetition, and severely impaired naming: on the Boston Naming Test, GL scored only 23%, and did not respond to phonemic cues. Her errors were mainly phonemic paraphasias. Aspects of GL's performance have been reported elsewhere (see, e.g. Dell et al., 1997; Foygel & Dell, 2000; Wilshire, 2002).

Testing began for our study in June 1997, five and a half years after GL's stroke, at age 49. At this time, GL's speech was fluent and informative, but still retained a slightly slowed, deliberate quality. There were frequent word-finding pauses and also occasional phonemic and semantic paraphasias. As shown in Table 1, GL made several errors on the PALPA phoneme discrimination task. However, she had a digit span of one (see below), so this task, in which two spoken words must be compared, may have been beyond her memory capabilities. Her performance on the phonological word-picture matching task, which may have been a better measure of her phonological input processing abilities, was extremely good. Performance on lexical-semantic tasks, such as word-picture matching and synonym matching, was at ceiling. GL's digit span was estimated at less than two: she passed only three of the ten two-digit items on the PALPA test.

On picture naming, GL showed clear length effects: on the Length and Frequency Naming Test, she correctly named 45% of monosyllables, but only 29% of bisyllables and 29% of polysyllables. The length effect was significant in a logistic regression analysis for length and frequency (parameter estimate of length: Wald  $\chi^2 = 4.17$ ,  $P < 0.05$ ). There was a non-significant trend towards a frequency effect: scores on high, medium and low frequency groups were 44, 32 and 27% respectively, Wald  $\chi^2 = 1.83$ ,  $P = 0.18$ , ns. GL's performance on the Task Effects Test (Table 1) suggests her word production difficulties were more pronounced in naming than in reading or repetition, but unlike IG, she also made a considerable number of errors even on the latter two tasks. On both reading and repetition, phonemic paraphasias were the most common error type, followed by formal paraphasias (a detailed analysis of errors in picture naming appears below). On the word/nonword task, GL correctly repeated 12 of the 20 real words, but only 7 of the 20 nonwords.

It can be seen from Table 2 that GL's errors in naming were predominantly phonological. The most common error type was the phonemic paraphasia (e.g. *trumpet* → /trʌŋklət/; *platypus* → /pædəpʊs/), but there was also a sizeable number of formal paraphasias (e.g. *heart* → "harp"; *saddle* → "scandal"). Semantic errors (e.g. *computer* → "telephone") and mixed errors (e.g. *elevator* → "escalator") were relatively rare. "Other" errors consisted mainly of neologisms (e.g. *accordion* → /zɪlɒp/) and fragmented attempts (e.g. *cork* → /krʌ-/...cork; *bagpipes* → /pai-/). On 53% of the items on which she made an incorrect first attempt, GL ultimately named the target correctly.

In GL's phonological errors (phonemic and formal paraphasias), phonemes early in the word tended to be better recalled than later ones. At each of the five successive Wing and Baddeley (1980) normalised word positions, the preservation rates were 87, 58, 59, 55 and 57%, respectively. This position effect was significant on a repeated measures logistic regression analysis for position on accuracy (Empirical standard error estimate for

position: Wald  $\chi^2 = 24.82$ ,  $P < 0.0001$ ). Further, the trend towards a “primacy” effect held for both phonemic paraphasias and formal paraphasias considered alone: accuracy at initial and final positions was 89 and 60%, respectively for phonemic paraphasias, and 77 and 45% for formal paraphasias. Wilshire (2002) describes some other characteristics of GL’s phonological errors: for example, they were generally quite distant from their targets (target-error phonological overlap was the second lowest in a cohort of seven patients), and contextual errors, such as anticipations and perseverations, did not occur at a rate greater than chance.

#### 4.2.1. Summary and comment

GL, like IG, suffers from a relatively selective impairment in word production: her comprehension is well-preserved, even on stringent matching tests, and her speech is largely fluent but contains word-finding pauses and some outright errors, and she performs poorly on constrained tasks such as picture naming. In picture naming, the majority of GL’s errors are phonemic paraphasias. Formal paraphasias are also common, accounting for around a third of all phonological errors on our test. Given that a large proportion of our naming targets were bisyllables and polysyllables, which tend to have relatively few close phonological neighbors, this rate is considerably higher than would be expected by chance (indeed, it is higher than that observed for most other patients tested on these materials: See Wilshire, 2002).

Within classical functional architecture models of language processing, the production of phonemic paraphasias can indicate either one of two different types of impairment: (a) in inability to access full representations from the phonological output lexicon; or (b) an impairment to the phonological output buffer. These two alternatives are often quite difficult to distinguish, because there are few clear predictions as to the expected differences. Nevertheless, GL’s profile does seem to suggest at least some impairment to the phonological output lexicon: she performs at a much higher level on tasks where the lexicon can be by-passed, such as single word repetition and reading, than on lexically driven tasks such as picture naming. Also, her phonologically related errors themselves show sensitivity to lexical status (a large proportion are formal paraphasias). However, it could be argued that the output buffer is also impaired: the phonological errors GL sometimes produces in reading and repetition, and the serial position effects in her phonological errors would certainly be consistent with this account (see esp. Kohn, 1989; Kohn & Smith, 1994, 1995, for similar arguments).

In terms of a two stage model of word production, GL would be characterised as having a primary deficit in phonological encoding—that is, in one or more of the processes involved in generating a complete phonological plan for the word. In the Dell model, GL’s high rate of phonemic paraphasias would indicate a problem activating the target word’s phoneme representations: activation reaching the phoneme level may be weak or alternatively, activation levels within the phonemes themselves may be noisy or unstable. The fact that GL’s phonological errors showed a strong “primacy effect” suggests that in her case, the deficit particularly affects word-ending phonemes (we return to this point below). In addition, according to some accounts, the high incidence of formal paraphasias might also indicate some degree of

impairment in activating lexical representations; again, we will return to this issue in Section 7.

## 5. Experiment 1: phonological priming with three types of primes

Experiment 1 investigates the effect of various types of phonological primes on IG and GL's picture naming (both accuracy and latency to respond). These include: begin-related (e.g. *ferry-feather*), end-related (e.g. *brother-feather*) and CV structure sharing (e.g. *shovel-feather*). Primes are presented auditorily and repeated aloud.

### 5.1. Method

#### 5.1.1. Materials

The picture targets used for each patient were selected from a pool of pictures compiled from a number of sources, which consisted mainly of black-and-white line drawings (a small number were coloured to enhance recognisability). All had elicited at least 80% name agreement on pilot tests involving ten normal speakers. The set of pictures used as targets with each patient was designed to contain as many as possible that had previously caused them difficulty during a standard naming task. For IG, the set used consisted of 50 pictures, with names of two to three syllables, whose Celex lemma frequencies (Baayen, Piepenbrock & van Rijn, 1993) ranged from 0.15 to 42.92 occurrences per million ( $M = 6.31$ ,  $SD = 8.45$ ). For GL, whose naming performance was poorer than IG's, the set used comprised 40 pictures, all of which had names of two syllables, and whose frequencies ranged from 0.15 to 42.29 occurrences per million ( $M = 8.37$ ,  $SD = 11.12$ ). Appendix A contains a list of all targets used.

For each target word, four primes were selected: a Begin-related prime (e.g. *ferry-feather*), an End-related prime (e.g. *brother-feather*), a Structure prime (e.g. *shovel-feather*) and an Unrelated prime (e.g. *auction-feather*). All primes were real words, and had the same number of syllables as their targets. Begin-related primes generally shared the target's entire first syllable, or if this was not possible, the maximum possible number of phonemes from initial phoneme onwards. No phonemes were repeated between target and prime at any other corresponding position in the word. End-related primes shared the target's final syllable, or if this was not possible, the maximum number of phonemes from the final phoneme backwards. Wherever possible, Begin-related and End-related primes also had a different CV structure to the target. Structure primes had the same CV structure as the target, but contained none of the same phonemes at corresponding positions (excluding unstressed vowels). Unrelated primes shared no phonemes with the target in a corresponding position, and were maximally different with respect to CV structure. A complete list of primes is given in Appendix A.

#### 5.1.2. Procedure

The experiment was run between October and December 1997. Stimuli were displayed using the *PsyScope* software (1994). Trials proceeded as outlined in Fig. 2. At Step 1, the prime was presented auditorily over computer speakers, accompanied by a visual fixation point on the screen. If the subject successfully repeated the word, Step 2 was initiated.



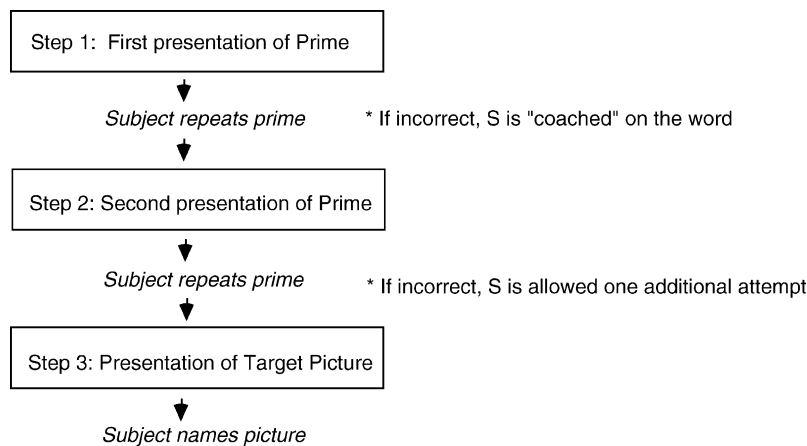


Fig. 2. Experiment 1. Outline of priming procedure. Steps 2 and 3 were initiated manually by the experimenter immediately following the preceding response.

If not, the subject was “coached” until he/she correctly repeated the word: first, the prime was presented orally for repetition. Then specific cues were offered; these included providing the first syllable of the word, presenting the word syllable-by-syllable (ca...mel), and using exaggerated mouth movements. Step 2 was initiated as soon as the prime was correctly repeated, or failing that, after all types of cues had been given. At Step 2, the prime word was presented a second time over the speakers. As soon as the word was successfully repeated, the experimenter immediately pressed a key to initiate Step 3. If the word was not successfully repeated, the subject was given one final chance to repeat it from the experimenter’s spoken model. As soon as a response was made, whether correct or incorrect, Step 3 was immediately initiated. At Step 3, the target picture was presented, accompanied by a tone. The picture remained in view until the subject had completed his/her naming attempt.

The experiment was administered across 4 testing sessions, separated by at least 1 week. Each target picture was presented only once per session. An equal number of items from the four different conditions (Begin-related, End-related, Structure, and Unrelated) was included in each session. Presentation order was pseudo-randomised, with no more than two items from the same condition appearing in succession. Sessions began with six practice items. The subject could break at any time between trials. Sessions were tape-recorded and double-transcribed by two trained, native English speakers. Discrepancies were passed on to a third transcriber, and then resolved in favour of the majority opinion. In cases of continued disagreement, resolution was in favour of the alternative closest to the correct phoneme.

### 5.1.3. Error and statistical analysis

For the analysis of naming accuracy, the first response to each target picture was scored. Only the target name was accepted as correct. The effect of the Begin-related, End-related and Structure primes was analysed by performing separate comparisons between each of these three conditions and the baseline, Unrelated condition. Logistic regression analysis

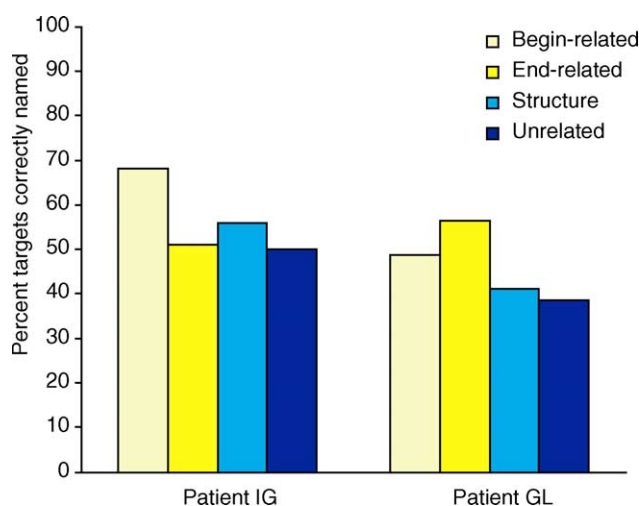


Fig. 3. Experiment 1. Percentage of targets correctly named (on first attempt) in each of the four priming conditions.

was used; for each comparison, independent variables were Prime Type (entered as a repeated measure) and Session Number. The model was fitted using Generalised Estimating Equations, and run on SAS version 6.12 (GENMOD procedure). Parameter estimates reported in the text use empirical standard error estimates. For the analysis of naming latencies, only trials that elicited a correct response on all four conditions were analysed. Outliers were excluded (latencies more than 2.5 standard deviations from the mean for a given subject/condition). Naming latencies were measured manually from digitised tape recordings; measurements were taken from the onset of the target picture (indicated by a “beep”) to the onset of the first correct response. An analysis of variance was performed for each of the three critical comparisons. Independent variables were Prime Type and Session Number. All hypotheses were one-tailed unless otherwise stated.

## 5.2. Results

### 5.2.1. Patient IG

IG correctly repeated 96% of the prime words on his final attempt. Of all the target pictures presented, he correctly named 56%: he named 46% in the first session, and 56, 58 and 65% in the second, third and fourth sessions, respectively (his score on the same pictures in a standard naming task given some weeks earlier was 56%). Fig. 3 shows IG's performance in each of the four priming conditions, collapsing across the four sessions. IG was most accurate in the Begin-related condition; the difference between this and the baseline, Unrelated condition was significant,  $z = 2.59$ ,  $P < 0.005$ . There was no difference between the End-related and Unrelated conditions,  $z = 0.286$ ,  $P = 0.39$ , nor between the Structure and Unrelated conditions,  $z = 0.89$ ,  $P = 0.19$ .<sup>3</sup>

<sup>3</sup> If we exclude trials where the prime word was never successfully repeated, the major differences between conditions are preserved. Percentages correct on the four conditions were as follows: Begin-related: 68%; End-related 50%; Structure 61%; Unrelated 49%.

Table 3  
Experiment 1. Naming latencies for correct naming responses

Condition	Patient IG		Patient GL	
	<i>N</i>	Mean RT (SD)	<i>N</i>	Mean RT (SD)
Begin-related	16	1.97 (1.00)	24	4.62 (1.51)
End-related	16	7.51 (6.19)	24	2.64 (4.85)
Structure	16	6.55 (6.81)	24	6.61 (6.17)
Unrelated	16	3.90 (4.21)	24	4.84 (4.72)

Table 3 shows mean naming latencies for IG's correct responses for each of the four conditions. Latency trends mirrored those obtained in the accuracy analysis. Latencies were significantly shorter in the Begin-related than in the Unrelated condition,  $F(1, 16) = 3.52$ ,  $P < 0.05$ . However, neither the End-related nor the Structure conditions elicited faster naming responses than the Unrelated condition. Indeed, for each of these, the difference obtained was actually in the *reverse* direction to that expected (End-related:  $F(1, 16) = 4.44$ ,  $P < 0.05$ ; Structure:  $F(1, 16) = 3.05$ ,  $P < 0.05$ ).

Table 4 shows the breakdown of errors in each of the priming conditions, based on the error classifications used for the analysis of standard naming reported above. Data from the Structure and Unrelated conditions are collapsed, because these did not differ significantly in terms of overall accuracy. Across all conditions, IG's most common error type—aside from Omissions and “Other” errors—was phonemic paraphasias (e.g. *submarine* → /sʌmbərɪn/), followed by mixed errors (e.g. *telescope* → “periscope”) and semantic paraphasias (e.g. *barrel* → “keg”; *pyramid* → “sphinx”). However, it was

Table 4  
Experiment 1. Breakdown of error types

Error type	Percentage of responses			
	Begin-related	End-related	Structure/Unrelated	Overall
<i>Patient IG</i>				
Phonemic paraphasia	12.0	10.2	10.1	10.6
Formal paraphasia	4.0	2.0	2.0	2.5
Semantic paraphasia	2.0	8.2	3.0	4.0
Mixed error	6.0	4.1	6.0	5.6
Omission	0.0	18.4	12.1	11.1
Other	8.0	6.1	14.1	10.6
<i>Patient GL</i>				
Phonemic paraphasia	17.9	23.1	30.8	25.6
Formal paraphasia	10.3	5.1	10.3	9.0
Semantic paraphasia	0.0	0.0	0.0	0.0
Mixed error	0.0	0.0	1.3	0.6
Omission	15.4	12.8	14.1	12.8
Other	7.7	2.6	3.8	4.5

Data for Structure and Unrelated conditions are collapsed into a single category (Structure/Unrelated).

“Other” errors that appeared to be the most responsive to the critical priming manipulation: these errors were significantly less common in the Begin-related than in the Unrelated condition,  $\chi^2(1, N = 5) = 5.00$ ,  $P < 0.01$ . None of the other differences reached significance. However, error totals were small (the maximum number of errors of any one type in any condition was 10), so this data allows us to draw only limited conclusions.

### 5.2.2. Patient GL

GL performed the priming task well, although she made slightly more errors in prime repetition than IG, repeating only 86% of primes correctly on the final attempt. Of all target pictures presented, GL correctly named 46%; her naming scores were 51, 51, 32 and 50% in the four sessions, respectively (on a standard naming test given some week’s earlier, her score on these targets was 25%). As can be seen in Fig. 3, GL successfully named more pictures in the End-related condition than in the baseline, Unrelated condition. This difference was significant,  $z = 1.73$ ,  $P < 0.05$ . There was also a trend towards better performance in the Begin-related than the Unrelated condition, but this failed to reach significance,  $z = 1.08$ ,  $P = 0.14$ . There was no significant difference between the Structure and Unrelated conditions,  $z = 0.23$ ,  $P = 0.41$ .<sup>4</sup> Table 3 shows mean naming latencies for GL’s correct responses. Again, trends were very similar to those obtained for naming accuracy: latencies were significantly shorter in the End-related than in the Unrelated condition,  $F(1, 24) = 6.77$ ,  $P < 0.01$ . Neither of the other critical comparisons was significant.

Table 4 shows the breakdown of GL’s errors across the various priming conditions. In all conditions, the vast majority of GL’s errors were phonological. If we exclude Omissions and “Other” errors, phonemic paraphasias formed the largest error group (e.g. *needle* → /nɪdəl/), followed by formal paraphasias (e.g. *antler* → “anchors”). Semantic paraphasias and Mixed errors were rare. Formal paraphasias appeared to respond best to priming; these errors tended to be less common in the End-related condition. Phonemic paraphasias, on the other hand, were actually slightly *more* common following End-related primes than Begin-related ones. However, none of these differences reached significance for this small error sample.

### 5.2.3. IG and GL: combined analysis

These data so far indicate a double dissociation between IG and GL with respect to their relative responsiveness to the Begin-related and End-related priming conditions. As shown in Fig. 4, there is a clear crossover in the two patients’ relative performance across these two conditions, with IG performing better in the Begin-related than in the End-related condition, and GL showing the reverse pattern. An additional statistical analysis was performed on the data from the Begin-related and End-related conditions to examine whether this interaction between patient (IG or GL) and prime type (Begin-related or End-related) was significant. A simultaneous logistic regression analysis was performed entering the following as independent variables: Patient (IG vs. GL), Session, Prime type

<sup>4</sup> Excluding trials where the prime was never successfully repeated, percentage correct are as follows: Begin-related: 52%; End-related 55%; Structure 41%; Unrelated 40%.

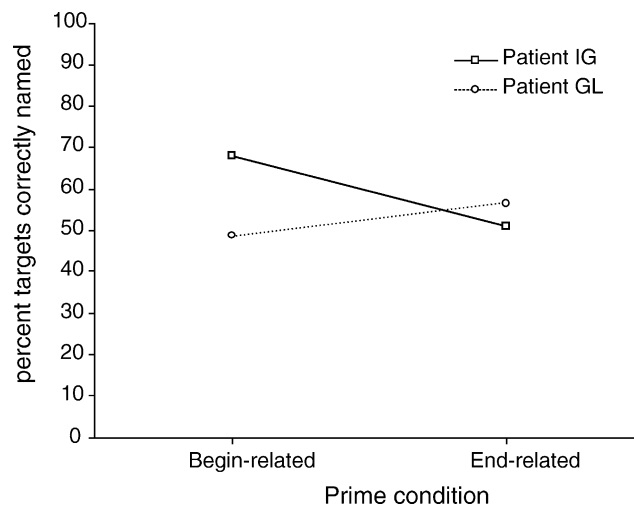


Fig. 4. Experiment 1. Percentage of targets correctly named for the Begin-related and End-related prime conditions, respectively.

(Begin-related vs. End-related) and Patient  $\times$  Prime type (interaction term).<sup>5,6</sup> Using a two-tailed test, the parameter estimate for Prime type was significant ( $z = 2.68$ ,  $P < 0.01$ ), while that for Patient fell just short of significance ( $z = 1.80$ ,  $P = 0.07$ ). The Patient by Prime type interaction was significant ( $z = 1.97$ ,  $P < 0.05$ ).

A similar analysis was performed on the latency data for the two patients (Begin-related and End-related prime conditions only). Using data prepared in the same way as for the main latency analysis, a mixed analysis of variance was performed; Independent variables were Patient, Session and Prime type (Begin-related vs. End-related), and a Patient  $\times$  Prime type interaction term was also included in the model. Using a two-tailed test, the main effect of Patient failed to reach significance ( $F(1, 54) = 0.77$ ,  $P = 0.38$ , ns). The main effect of Prime type was significant ( $F(1, 54) = 5.40$ ,  $P < 0.05$ ). The interaction between Patient and Prime type was highly significant ( $F(1, 54) = 27.25$ ,  $P < 0.0001$ ).

#### 5.2.4. Summary and Comment

The results of Experiment 1 show that for both IG and GL, picture naming can be facilitated by the prior repetition of phonological primes. However, the two patients responded differently to the two key prime types: IG showed significant priming effects only with begin-related primes (increased accuracy and faster latencies to respond), whereas GL showed significant effects only with end-related primes (increased accuracy and faster latencies). For GL, there was a small trend towards an effect with begin-related

<sup>5</sup> A more conventional Patient  $\times$  Position  $\times$  Relatedness analysis could not be performed, because this was not a complete  $2 \times 2 \times 2$  design. Rather, it included only one Unrelated condition which serves as a baseline for all others.

<sup>6</sup> Prime type was a repeated measure within patients, but because the stimuli used were different for IG and GL, this was not a repeated measure across patients.

primes but this failed to reach significance for either the accuracy or latency data. Combined analyses revealed significant interactions between patient and prime type for both accuracy and latency data. The patients therefore showed a clear double dissociation in their responsiveness to the two key priming conditions.

Before proceeding, let us briefly consider our findings within the context of a traditional multi-component model of aphasic language impairment. In the popular [Patterson and Shewell \(1987\)](#) scheme, word production involves three major processing modules: the cognitive/semantic system, the phonological output lexicon and the response buffer. Within this framework, IG's excellent comprehension, together with his mix of phonological and semantic errors and his word frequency effects in naming, would all point to a primary impairment accessing representations within the phonological output lexicon. His response to begin-related primes would indicate that these primes facilitate access to the target's entry in the phonological output lexicon. Perhaps the prime word might aid IG in locating the site of the target's lexical-phonological entry (if entries were organised by form, this would be a plausible account), or perhaps there might be cross activation between the representations of similar sounding words. In GL's case, her high rates of phonological errors, her tendency to produce formal paraphasias, and her particularly poor performance on conceptually driven tasks such as naming, all suggest at least some impairment to the phonological output lexicon. But in this case, the response buffer might also be implicated. If this were the case, we could explain the present findings by proposing that end-related primes operate primarily at the level of the response buffer. If word-ending phonemes are more subject to decay than beginning phonemes (which would be plausible if all phonemes enter the buffer at the same time, but the end phonemes must wait longer to be articulated), then a prime containing these end phonemes may be more effective at offsetting the effects of decay than one sharing earlier phonemes. This account of the priming effects certainly seems plausible, but it falls short of a full explanation of the phenomenon. Firstly, in IG's case, it is unclear just what mechanism gives rise to the facilitation effects, and why these should favour words that share early, rather than late, phonemes. One could say it offers a description, rather than an explanation, of the phenomenon. And in GL's case, it is unclear just how the phonological representation of the end-related prime is stored, and more importantly, how it remains available at the time of subsequent target production, especially in a patient whose output buffer is not functioning effectively.

Let us now turn to the more explicit, Dell model. The current findings can be explained elegantly within this model if we make one modification: we propose that a word's phonemes are activated in sequential order. In this model, both begin-related and end-related primes should result in phonological facilitation. However, begin-related primes would have greater potential to facilitate *lexical selection* than end-related primes, because the phonemes shared between prime and target are encoded early, and have maximal opportunity to influence the lexical level via feedback activation. Therefore, IG, whose errors in naming suggest some impairment at the lexical selection stage, would be expected to benefit more from begin-related than end-related primes. On the other hand, GL, whose impairment appears to be largely confined to the phonological encoding stage, would not be expected to show such an advantage. This account, in its pure form, predicts that GL should be equally facilitated



by both types of primes. However, this is not what was observed: GL showed reliable effects only with end-related primes. In standard naming, GL shows primacy effects—that is, better recall of early than later phonemes. Therefore, primes containing the difficult end phonemes may simply have more *potential* to improve overall production accuracy than those containing the more accessible beginning phonemes. An alternative explanation is that the patterns of activation in phonological nodes at the time of target production are themselves asymmetric. We consider this interesting alternative at the end of the paper.

Turning now to the qualitative analyses of errors, these also suggest a difference in the primary locus of the priming effects in each patient. For IG, the primary effect of begin-related primes was to decrease the incidence of non-phonological errors—most notably, “Other” errors. In contrast, for GL, it appeared that the primary effect of the final primes was to reduce the number of formal paraphasias (although this fell short of significance). However, many questions still remain unanswered. For example, the error types that are most commonly associated with impairment to the stages of word production implicated in each individual—semantic errors in the case of lexical selection and phonemic paraphasias in the case of phonological encoding—did not appear to be significantly affected by the priming manipulations in either patient. These questions will be considered in Section 7.

One puzzling finding was that, in the naming latency analyses, IG’s latencies were actually *slower* in the End-related and Structure-sharing conditions than in the Unrelated condition. This inhibitory priming effect is unexpected, given that our paradigm was chosen to elicit facilitation. One previous explanation for inhibitory phonological priming effects is that the processing of the target causes reactivation of the representations of the prime word, particularly its phonological representations. These representations then compete for selection with those of the target, causing a delay in production (O’Seaghdha et al., 1992; O’Seaghdha & Marin, 2000; Peterson, O’Seaghdha, & Dell, 1996). This account may offer a plausible explanation for the effects seen in IG. The proposed reactivation mechanism operates at the phonological encoding level, and relies on successful activation of the target lexical representation in the first place. Therefore, while it might increase word production latencies for correctly selected lexical items, it would be expected to have little influence on the actual probability of correct lexical selection. This would explain why IG’s latencies increased in the End-related and Structure conditions, but his overall accuracy was unaffected.

A second surprising observation was that overall, IG produced consistently more phonemic paraphasias in this experiment than semantic paraphasias—unlike in standard naming, where these two error types were roughly equally common. This is unlikely to be due to any spontaneous change in IG’s condition (he was more than nine years post-stroke before testing began, and these tasks were separated by no more than four months), nor does it appear to be due to the particular pictures tested (the same 50 target pictures yielded 10% semantic paraphasias and 6% phonemic paraphasias when given in standard naming). The reason for this change therefore remains unclear. Nevertheless, whatever its basis, it certainly indicates that IG’s deficit manifests itself variably in the production of either semantic paraphasias or phonemic paraphasias, depending upon the situation. We will consider this issue further in Section 7.

## 6. Experiment 2: replication and further exploration of the major priming effects

The findings of Experiment 1 are based on a very small sample of data—there were between 40 and 50 targets per participant, and the changes in naming accuracy from best to worst condition were of the order of seven to nine items. The small sample size also meant that qualitative analyses of errors were based on no more than 10 errors per category. In Experiment 2, we replicate the main findings from Experiment 1 using a different set of stimuli and a more powerful design. Here, we focus on just one type of prime per subject—that which generated the most reliable facilitation in Experiment 1 (begin-related primes for IG and end-related primes for GL). A new set of 40 picture targets is tested for each patient, and each prime-target combination is tested twice. Experiment 2 also incorporates two further changes. First, each picture target is preceded by three primes, rather than just one; only the last prime is manipulated with respect to its phonological content. Second, we include an orthogonal manipulation of CV structure. While Experiment 1 showed that primes sharing the target's CV structure alone did not facilitate naming, it is still possible that the *combination* of shared form and structure may be more facilitatory than shared form alone, particularly if structure is primed repeatedly.

### 6.1. Method

#### 6.1.1. Materials

A new set of 40 picture targets was selected for use with each of the aphasic participants. These sets were again tailored to each participant, and were designed to contain as many pictures as possible that had previously caused difficulty for that person during standard naming. The pictures used included black and white line drawings and, where the target could not be reliably depicted in this way, coloured drawings and photographs. All had bisyllabic names. All had been piloted on a group of ten normals and had elicited at least 80% name agreement. For both patients, the target picture names ranged in frequency from 0 to 107.33 occurrences per million, although their average frequency was slightly lower for IG ( $M = 12.09$ ,  $SD = 22.38$ ) than for GL ( $M = 13.59$ ,  $SD = 23.49$ ). There was a high degree of overlap in the pictures used for each participant (see Appendix A for a list of the target picture names).

Each target picture was preceded by three primes. The prime conditions examined were different for each participant: For IG, the Begin-related condition was examined but not the End-related condition, whereas for GL, the reverse was the case. In addition, the CV structure of targets and primes was manipulated independently of their phonological content, so that half the prime-target sets in each condition shared the same CV structure (e.g. *lava silo coma* → *genie*) and half had different CV structures (e.g. *rifle satin puzzle* → *genie*). This design yielded four priming conditions for each participant: (a) *Phonemes + Structure*, in which primes shared the target's CV structure and the last prime also shared some of its phonemes (beginning phonemes for IG and end phonemes for GL); (b) *Phonemes Only*, in which primes had a different CV structure to the target but the last prime shared some of its phonemes; (c) *Structure Only*, in which primes and targets shared CV structure but not phonemes; and (d) *Unrelated*, in which primes and targets shared neither CV structure nor phonemes. All primes were real, bisyllabic words.

As previously, phoneme-sharing primes generally shared one entire syllable with the target, but where such a match did not exist, the next best match was chosen.

### 6.1.2. Procedure

The experiment was run between February and March, 1999. The procedure used was the same as for Experiment 1, with two exceptions. First, three primes were presented prior to each picture target. Second, participants repeated each prime word a minimum of three, rather than two times: at the beginning of a trial, each prime word was presented twice for repetition according to the procedure outlined in Experiment 1; then, following this, the three primes were each presented again, once only. As soon as a response was made to this final presentation, whether correct or incorrect, the next stimulus was initiated.

### 6.1.3. Error and statistical analysis

Responses were scored as for Experiment 1. Naming accuracy data was submitted to a repeated measures logistic regression analysis; independent variables were Phoneme Content (whether the last prime shared phonemes with the target), Structure (whether primes and target shared CV structure), and Session Number. As previously, the model was fitted using Generalised Estimating Equations, and parameter estimates reported are empirical standard error estimates. Naming latency data was collected in the same way as previously, and submitted to a repeated measures mixed model analysis; independent variables were Structure, Phoneme Content and Session number. Picture targets with missing latency values (targets not correctly named on at least one occasion) were excluded. Outliers were also excluded using the same criterion as before. Again, all hypotheses are one-tailed unless otherwise stated.

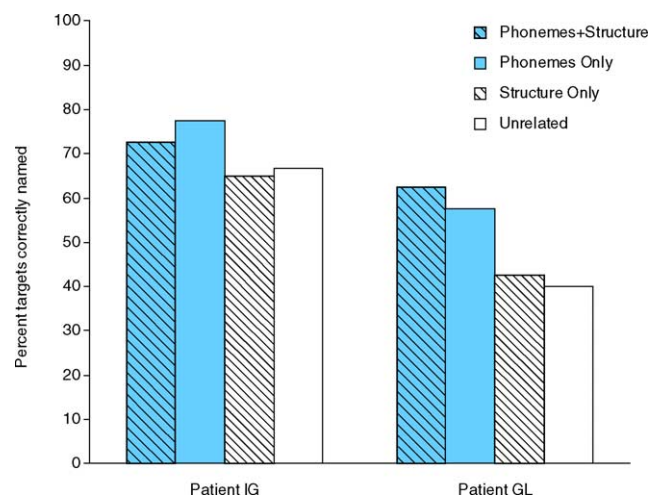


Fig. 5. Experiment 2. Percentage of targets correctly named by IG and GL in each of the four prime conditions.

Table 5  
Experiment 2. Naming latencies for correct naming responses

Condition	Patient IG		Patient GL	
	<i>N</i>	Mean RT (SD)	<i>N</i>	Mean RT (SD)
Phonemes + structure	16	2.68 (3.03)	21	2.20 (1.57)
Phonemes only	16	2.07 (1.51)	21	2.90 (1.98)
Structure only	16	4.15 (2.81)	21	4.02 (3.07)
Unrelated	16	4.39 (3.07)	21	3.34 (2.44)
Overall	16	3.32 (2.80)	21	3.11 (2.38)

## 6.2. Results

### 6.2.1. Patient IG

Fig. 5 shows the percentage of targets correctly named by IG and GL in each of the four conditions. It can be seen that for IG, naming accuracy was higher in “phoneme sharing” conditions (that is, where the last prime was begin-related) than in “non-phoneme-sharing” conditions. This phoneme content effect was significant,  $z = 1.21$ ,  $P < 0.05$ . There was no effect of Structure,  $z = 0.38$ ,  $P = 0.35$ . As shown in Table 5, latency trends again mirrored the accuracy trends. Latencies were faster in phoneme sharing than in non-phoneme-sharing conditions  $F(1, 16) = 8.73$ ,  $P < 0.01$ . There was no significant effect of Structure.

Table 6 shows the breakdown of errors in phoneme-sharing and non-phoneme-sharing conditions. Data are collapsed across the structure manipulation, as this had no significant effect on naming accuracy. Unlike Experiment 1, where phonemic paraphasias were

Table 6  
Experiment 2. Breakdown of error types across Phoneme Sharing conditions (Phonemes ± Structure and Phonemes Only combined) and No Phonemes Shared conditions (Structure Only and Unrelated combined)

Error type	Percentage of Responses		
	Phoneme Sharing	No Phonemes Shared	Overall
<i>Patient IG</i>			
Phonemic paraphasia	6.5	2.5	4.4
Formal paraphasia	1.3	1.3	1.3
Semantic paraphasia	7.5	7.6	7.5
Mixed error	2.5	0.0	1.3
Omission	7.5	13.9	10.7
Other	2.5	8.9	5.7
<i>Patient GL</i>			
Phonemic paraphasia	20.0	21.3	20.6
Formal paraphasia	5.0	17.5	11.2
Semantic paraphasia	2.5	0.0	1.3
Mixed error	1.3	1.3	1.3
Omission	8.8	15.0	8.8
Other	7.7	2.6	4.5

the most common error, here semantic paraphasias were the most common (e.g. *bacon* → “sausage”). There was also a higher incidence of “Other” errors, most of which were interrupted, fragmented attempts that could not be reliably categorised (e.g. *rocket* → /lɛ-/.../mɪʃ-/). With respect to the influence of the priming manipulations, the most noticeable trend is in Omissions and “Other” errors, which tended to be less common in the phoneme-sharing conditions. However, these differences failed to reach significance (“Other” errors:  $\chi^2(1, N = 159) = 1.11, P = 0.29$ ; Omissions:  $\chi^2(1, N = 159) = 1.94, P = 0.16$ ). Phonologically related errors were not reduced in the phoneme-sharing conditions, but rather showed a slight (but non-significant) trend in the *reverse* direction.

#### 6.2.2. Patient GL

As shown in Fig. 5, GL’s naming accuracy was higher on the phoneme-sharing conditions than the non-phoneme-sharing conditions,  $z = 2.80, P < 0.01$ . There was no effect of Structure,  $z = 0.54, P = 0.29$ . As shown in Table 5, naming latency trends again mirrored those obtained for accuracy: the main effect of Phoneme Content was significant,  $F(1, 21) = 4.39, P < 0.05$ . There was no significant effect of Structure.

As can be seen in Table 6, GL’s error composition was very similar to that observed previously. Again, most errors were phonological, with phonemic paraphasias making up the largest single error group (e.g. *genie* → /bini/; *muzzle* → /mædəl/), followed closely by formal paraphasias (e.g. *pedal* → “paddle”). The error type which appeared to be most strongly influenced by the phoneme content manipulation was formal paraphasias. This effect was significant,  $\chi^2(1, N = 160) = 5.07, P < 0.05$ . “Other” errors were also less common in the phoneme-sharing conditions, but this difference failed to reach significance ( $\chi^2(1, N = 160) = 0.96, P = 0.32$ ). Phonemic paraphasias did not appear to be influenced by the phoneme content manipulation.

#### 6.2.3. Summary and comment

The results of Experiment 2 successfully replicated the key findings of Experiment 1 using a different set of materials and a more powerful design. IG again showed facilitation with begin-related primes and GL again showed facilitation with end-related primes. Therefore, the main effects obtained in Experiment 1 cannot be attributed to idiosyncratic aspects of the targets used with each individual. In the accuracy analyses, the orthogonal manipulation of CV structure failed to generate any significant effects, even using this robust, triple-prime design. This would seem to indicate that CV structure, either alone, or in combination with shared phonological content, does not facilitate processing at the impaired stage in either of our patients.

Of course, the data from Experiment 2 do not speak directly to the issue of the relative effectiveness of begin-related and end-related primes for each individual, because only one type of prime was tested for each patient. Nevertheless, the error type analyses, which are consistent with Experiment 1, do suggest a different locus for the priming effects in IG and GL. For IG, conditions incorporating begin-related primes elicited fewer “Other” errors than non-phoneme-sharing conditions, but the incidence of phonological errors did not decrease (neither phonemic nor formal paraphasias). For GL, on the other hand, the primary effect of the end-related conditions was to reduce the incidence of formal paraphasias. It is interesting to observe that, as previously, the “classic” error

types—semantic paraphasias and phonemic paraphasias—were little affected by either phoneme content manipulation. Some possible reasons for this are discussed below.

One surprising observation concerned the nature of IG's errors. In Experiment 1, phonemic paraphasias outnumbered semantic paraphasias, whereas in Experiment 2 the reverse was the case. Again, it appears unlikely that this could be due to some fundamental change in IG's condition, because he was well beyond the acute phase of his illness. Certainly, the picture set used for IG in Experiment 1 included polysyllabic words, but the set used in Experiment 2 did not, and since longer words are generally more likely to elicit phonological errors than shorter ones, this may have contributed to the differences. Whatever the reason, this shift in error types provides another demonstration of the variability in IG's error patterns, and again raises the possibility that both phonemic and semantic errors might result from a single underlying impairment.

## 7. General discussion

This study examined phonological priming of production in two aphasic individuals, IG and GL. Both patients had selective impairments in word production. IG's error mix—which included failures to respond, semantic errors, phonological errors and mixed errors—suggested at least some impairment at the lexical selection stage, and perhaps also some accompanying impairment at the phonological encoding stage. GL, on the other hand, produced mainly phonological errors (phonemic paraphasias and formal paraphasias), suggesting a primary deficit involving the phonological encoding stage. The results of two experiments showed that phonologically related primes facilitated naming in these aphasic individuals, as has been found for normals (see Collins & Ellis, 1992). Nevertheless, unlike normals, who show facilitation (faster naming latencies) with both begin-related and end-related primes (see Collins & Ellis, 1992), our patients responded much more selectively. IG showed significant facilitation (both accuracy and latency) only with begin-related primes, whereas GL showed significant facilitation (both accuracy and latency) only with end-related primes, and no more than a nonsignificant trend towards facilitation with begin-related ones.

One compelling explanation for these contrasting priming effects is that the two types of primes operate at different stages of word production, with end-related primes acting mainly at the phonological encoding stage, and begin-related acting at the lexical selection as well as the phonological encoding stage. According to this “dual mechanism” account, IG, who has a significant impairment involving lexical selection, would be expected to benefit most from begin-related primes, because they influence the lexical selection stage. End-related primes would be less effective, because they operate mainly at the phonological encoding stage, and their effectiveness depends upon correct lexical selection in the first place. On the other hand, GL, whose primary impairment involves phonological encoding should show no such benefit. In fact, GL actually benefited *more* from end-related than begin-related primes, a point we will return to later. Below we provide a more detailed account of our findings within the context of the Dell model. We then discuss implications of the data for our understanding of normal and aphasic word production.



### 7.1. A simple interactive-activation model

The simple two-stage model of Dell and colleagues (e.g. Dell, 1986, 1988; Dell & O'Seaghdha, 1991; Dell et al, 1997) makes clear predictions concerning the origin of semantic and phonemic paraphasias in word production. Semantic paraphasias arise when the lexical node of another, related word becomes more highly activated than that of the target, resulting in a lexical selection error. Phonemic paraphasias arise when one or more of the target word's phoneme nodes fails to become sufficiently activated to win the competition for selection at the phonological encoding stage. In terms of this model, IG's production of semantic paraphasias in naming tasks would indicate that he sometimes fails to select the correct lexical node, perhaps because the activation reaching the lexical nodes is insufficient, or activation within the nodes themselves is noisy or unstable. IG's occasional phonemic paraphasias would suggest some additional impairment at the phonological encoding stage. However, since the Dell model is a cascading model—in which some activation spreads to phoneme nodes even before a single lexical node has been selected—at least some of these errors may arise indirectly from abnormalities at the lexical selection stage. This could happen if one or more competitor words becomes activated to a similar extent to the target, because each may significantly activate its respective phonemes, thereby increasing the chances of a phonological error (the variation we observed in IG's proportions of semantic and phonemic paraphasias from task to task would certainly be consistent with this idea).

On the other hand, GL would appear to suffer from a marked impairment involving the phonological encoding stage. Her high rates of phonemic paraphasias indicate a significant difficulty activating phoneme nodes—either the nodes do not receive sufficient activation, or their activation levels are noisy or unstable. In contrast, GL produced relatively few clear instances of lexical selection errors, such as semantic paraphasias, so this stage of processing appears to be largely preserved. More ambiguous are GL's formal paraphasias. In the Dell model, these errors can originate as a result of either a lexical selection failure or a phonological encoding failure. A lexical selection failure may give rise to a formal paraphasia if feedback activation causes the lexical node of a form-related word to become more activated than that of the target. These types of errors will occur in large numbers only if the target lexical node is frequently underactivated—that is, there is an impairment at the lexical selection stage. However, an alternative origin for formal paraphasias is at the phonological encoding stage. Any competing phoneme whose selection would result in the production of a real lexical item will receive more activation than one which does not, by virtue of feedback and feedforward between the lexical and phonological levels. GL's profile suggests many of her formal paraphasias may arise at the latter stage: she shows little independent evidence of an impairment in lexical selection (there are very few semantic paraphasias or other independent indicators of an impairment of this kind).<sup>7</sup>

<sup>7</sup> Recent modelling efforts by Foygel and Dell (2000) account for GL's high rates of formal paraphasias by proposing that she has an accompanying impairment at the lexical selection stage. However, as Wilshire and Fisher (2004) note, this model's fit to GL's data is uncomfortable. In particular, it significantly overpredicts semantic paraphasias (see Foygel & Dell, 2000, Table 4). Because GL's rates of semantic paraphasias are so low, there appears to be little independent basis for proposing an impairment at the lexical selection stage—other than for accounting for formal paraphasias.

According to the Dell model, a phonological priming trial proceeds as follows. The first event is auditory prime repetition. The Dell model has recently been extended to incorporate an auditory input system with direct connections to the phonological nodes (see Martin et al., 1994, 1996), and this is capable of modelling the repetition task. During auditory presentation of the prime word, the prime's phonological nodes become activated. This activation then automatically spreads up and down throughout the network. During this process, the prime's lexical node becomes activated, and so too do the lexical nodes of other words that contain some of the prime's phonemes. After a specified time period, the most highly activated phoneme nodes are selected and the prime word is produced. The activation levels of the selected nodes are then set to zero; nevertheless, activation in these nodes quickly builds up again as a result of feedforward and feedback activation with other activated nodes. Consequently, when the target picture is presented, the prime word's phonological nodes are still activated, as are the lexical nodes of a number of phonologically related words. Therefore, if the prime and target are phonologically related, the target's lexical and phonological nodes will be partially activated at the time target encoding begins.

In the model so far described, phonological encoding proceeds in parallel across the word. However, if this model is modified to incorporate sequential encoding of phonemes, it is capable of offering an elegant account of the asymmetries observed in our study. There are a number of mechanisms by which this could be accomplished (see, e.g. Dell, 1988; Houghton, 1990; Sevald & Dell, 1994). In this modified model, the patterns of activation that would build up during prime processing would be asymmetric with respect to word position: at the lexical level, words that shared the prime's early phonemes would receive more activation than those that shared later phonemes, because the shared phonemes would become activated earlier and therefore would have more opportunity to influence activation levels at the lexical level.

Now consider our results from the perspective of this modified model. Because the lexical selection stage is impaired in IG, he will benefit most from primes that can boost activation of the target lexical node. Of course, the benefits to IG might not necessarily be restricted to the lexical level; he may also benefit from activation enhancement within the target's phoneme nodes, particularly if he also has some impairment in phonological encoding. But there will be a clear benefit at the lexical selection stage. Begin-related primes will offer more activation support to the target lexical node than will end-related primes, so there will be a distinct advantage for these—and this is just what we observed. Somewhat more puzzling was the finding that begin-related primes tended to selectively reduce the incidence of “Other” errors (such as fragments) and possibly also omissions, but not semantic paraphasias. Our simple model predicts a reduction in semantic paraphasias, but makes no predictions regarding Other errors because these are ambiguous as to origin. One speculative hypothesis is that the change in error types reflects a general shift towards less “severe” errors. It is possible that Other errors and omissions are indices of a more serious disruption to lexical-level activation patterns than semantic paraphasias (that is, they are “bad errors” in the language of Schwartz et al. (1994)). If so, then any manipulation that improved the operation of the lexical selection stage would result in a shift in error types away from these “bad” error types. A second possibility is that Other errors/omissions are

actually selectively reduced by the begin-related primes. If Other errors and omissions reflect instances in which no single lexical node has become sufficiently activated to be selected in place of the target, they might therefore benefit more from begin-related primes because less activation is required to raise the lexical node significantly above its competitors.

In GL's case, we would predict a benefit from those primes that can enhance activation in the phonological nodes. Our model of the task proposes that both types of primes will be equally effective in this respect. However, GL actually showed a reliable benefit only for end-related primes. There are two possible explanations for this. The first is based on potential for improvement. We noted earlier that in standard naming, GL is better at producing word-beginning phonemes than later phonemes. Consequently, primes that contain the difficult, end phonemes of a word may be able to offer the greatest benefit, simply because they will have the greatest potential to effect a change in the overall accuracy. An alternative explanation is that the facilitation generated by the prime is itself asymmetric. This might occur for a number of reasons—for example, phonemes at later word positions may be more resistant to decay during the prime-target interval, or there may be fewer competitive influences affecting activation levels of word-ending phonemes during the prime-target interval. Studies of serial position effects in word repetition offer some support for this account. In word repetition tasks, some patients with a lexical-semantic impairment exhibit "recency effects" (Martin & Saffran, 1997). That is, they are better at producing the word's end phonemes than its beginning phonemes. If these patients, who presumably are unable to rely on lexical-semantic information to repeat words, instead rely heavily on its phonological representation, then the observed recency effect would indicate that the later phonemes of the word are retained better than the beginning ones. Indeed, in GL's case, there is some independent evidence that word-ending phonemes may have been easier to retain: when GL was required to repeat bisyllabic nonwords—a task which presumably loads heavily on the retention and reproduction of phonological representations and benefits little from lexical/semantic information—she showed recency effects (in her phonological errors, she correctly reproduced only 61% of word-initial phonemes, but 87% of word-final phonemes). However, this supporting evidence is, at best, indirect, and at present, it is not possible to distinguish definitively between these two competing explanations.

Turning now to the nature of the errors produced by GL in the priming task, the primary effect of end-related primes was to reduce the incidence of formal paraphasias. Again, the reasons for this are unclear. However, to offer a speculative account, we could refer back to the "good/bad error" argument we developed earlier for IG: if formal paraphasias are an indicator of a more serious disruption to phonological-level activation patterns than phonemic paraphasias, then any manipulation that improves overall phonological encoding accuracy would induce a shift towards fewer of these errors. At present, however, we have no independent data that formal paraphasias are indeed "bad errors" in this sense. An alternative possibility is that the specific reduction in formal paraphasias is related to dynamic aspects of GL's disorder. If the likelihood of formal paraphasias increases with continued reverberation of activation between the phonological and lexical levels, then any manipulation

which reduces phonological encoding time will have a particular benefit for reducing these types of errors. There were certainly indications that in GL, phonological encoding was pathologically slow: not only did her speech give the outward appearance of being extremely careful and deliberate, but in the control, Unrelated condition in Experiment 1, her naming latencies averaged nearly 5 s. Further, we have clear evidence from both experiments that end-related primes were indeed effective at reducing these latencies.

One further observation from our study warrants some discussion. We noted earlier that IG and GL were the only two patients from a group of seven to show significant effects of phonological priming on overall accuracy. The original cohort of patients tested on the priming task were all selected on the basis of their naming errors: all produced a significant number of phonological errors. However, IG and GL were distinguishable from the rest of the group on the basis of the other errors they produced. IG produced a much higher proportion of semantic paraphasias (20% of all IG's errors were semantic paraphasias, compared to between 3 and 12% for the other patients). If begin-related primes operate mainly at the lexical selection stage, then their effectiveness would be confined to patients with clear indications of an impairment at that stage of processing, such as IG. So it is perhaps not unexpected that IG was the only patient to show significant effects of begin-related primes. Patient GL produced proportionately more formal paraphasias than any of the other patients (23% of GL's errors were formal paraphasias, and for the other patients, the range was between 7 and 17%). We suggested earlier that the likelihood of formal paraphasias may increase with phonological encoding time, so it is possible that phonological primes are only of benefit in patients whose phonological encoding is extremely slow. This would certainly be consistent with the suggestion raised earlier that the phonological primes might operate by increasing the speed with which phonological encoding can be accomplished. Of course, there may be other reasons why our priming manipulations were effective for only a small proportion of patients. In order to generate priming effects, the prime must have the potential to influence events occurring during the subsequent naming attempt. Impairment to any one of a number of processes might reduce this potential. For example, patients who exhibit very long latencies to name pictures might be less responsive to priming simply because there is too much temporal separation between the cognitive events involved in prime and target processing. Further research will be required to tease out these possibilities.

In this discussion, we have explained our findings within the context of a simple two-stage Dell-type model. While this model is not without its problems (for some recent commentaries, see Rumel & Caramazza, 2000; Rumel, Caramazza, Shelton, & Chialant, 2000), we chose to base our account on it for two important reasons. First, it has been computer-implemented, and is therefore quite explicit with regard to its predictions, particular those relating to error phenomena. Second, the activation and selection mechanisms on which this model is based lend themselves nicely to the explanation of error patterns. An additional benefit was that the model's interactive properties offered a very simple and elegant mechanism for explaining several central phenomena: most notably, GL's high rate of formal paraphasias, and the capability

for phonological variables (such as prime-target phonological relatedness) to influence what appeared to be lexical-level processes in cases such as IG. However, none of these features is *essential* for explaining the main findings obtained here. For example, phonological primes could influence lexical-level processes not as a result of phonological to lexical feedback during prime phonological encoding, but rather during *recognition* of the prime word. Clearly, hearing and recognising an auditorily presented prime involves activating a lexical representation of that word, and also most probably those of other form-related words, and if recognition occurs in real time, this cross-activation could quite plausibly favour words that share early rather than late phonemes (see esp. Marslen-Wilson, 1975, 1987, for a model that explicitly incorporates this feature). This alternative account is equally plausible on the current data, but could in principle be tested in subsequent studies—for example, by manipulating the modality of presentation of prime (whether auditory, visual, or in picture form for naming), and/or whether the prime must be produced.

## 7.2. Implications for normal word production

The results of this study provide an additional source of support for a model of production that incorporates at least two stages, one involving lexical selection and the other, phonological encoding. The data are difficult, if not impossible, to explain without assuming that IG and GL have primary deficits involving different stages of the production process, in IG's case the lexical selection stage, and in GL's case the phonological encoding stage. But perhaps even more importantly, our results contribute to the mounting number of studies that demonstrate asymmetric effects in phonological encoding. Previous studies of aphasic word production have documented asymmetries in the phonological errors themselves—word-initial phonemes are generally more likely to be correctly produced than later phonemes (e.g. Kohn & Smith, 1994, 1995; Schwartz et al., 2004; Wilshire, 1998, 2002). However, this observation may simply reflect the patients' patterns of error monitoring and self correction. For example, if early phonemes are incorrect, the error may be more likely to be aborted, so the error would never be included in an analysis restricted to completed errors. The present data offer much stronger evidence for word position asymmetries by showing that patients can respond differently to phonological primes depending upon the location of the shared phonemes. These findings regarding the asymmetric effects of begin-related and end-related primes offer additional support for models of phonological encoding that incorporate sequential processing across word positions (e.g. Dell, Juliano, & Govindjee, 1993; Hartley & Houghton, 1996; Houghton, 1990; Meyer, 1991; Sevald & Dell, 1994; Vousden, Brown, & Harley, 2000).

Our findings with respect to the asymmetric effect of begin-related and end-related primes differ dramatically from those obtained with normal speakers. These studies have obtained little evidence for differences in the effects of begin-related and end-related primes, and this has led a number of researchers to conclude that part or all of the phonological encoding process takes place in parallel (see especially Collins

and Ellis, 1992; Meyer and van der Meulen, 2000). Our results suggest that phonological primes can indeed generate strong asymmetric effects, and that previous failures to obtain such effects may be due to limitations in the paradigms themselves. As noted earlier, the processes that take place during the two key stages of word production might be extremely rapid, and we do know that facilitatory effects of phonological priming are generally small. If the reductions in processing time are positive but small for both begin-related and end-related primes, then any differences in the precise stage at which each operates might be difficult to detect in naming latencies. The examination of aphasic individuals with carefully documented, selective deficits offers an alternative method of highlighting potential differences in the operation of these two types of primes.

### 7.3. *Implications for aphasia*

Cognitive Neuropsychological models from the early 1980's identified an aphasic condition in which word production was selectively impaired, but comprehension was relatively well-preserved (see Gainotti, Silveri, Villa and Miceli, 1986; Kay and Ellis, 1987). The present results offer persuasive evidence that this type of impairment can exhibit further fractionations. The two patients reported here both presented with a selective impairment in word production, but demonstrated a clear double dissociation in their response to the two critical priming manipulations. This is not the first study to report finer fractionations within the general category of word production deficits. Some previous studies have found that patients with this condition may vary with respect to the composition of their naming errors, and possibly also their relative performance across different word production tasks (see for example, Croot et al., 1999; Dell et al., 1997; Foygel & Dell, 2000; Rapp & Goldrick, 2000). However, the differences previously reported have not been sufficient to demonstrate a clear double dissociation. Our priming experiments provide much stronger evidence. Patients IG and GL, who, like previously reported patients, showed some variation in their error composition and in their relative performance across different word production tasks, exhibited *markedly* different performance in the two critical priming conditions. The most theoretically plausible account for this double dissociation is that word production impairments can selectively affect either one of the two stages currently proposed in speech production models—lexical selection or phonological encoding.

The present findings also have implications for our understanding of the phonemic cueing paradigm, a technique often used to relieve word retrieval difficulties in aphasic individuals. Recent phonemic cueing studies have obtained inconsistent results. Some report positive, facilitatory effects of the provision of an initial phoneme cue, whereas others report null effects in at least some patients (e.g. Howard, 1995; Li & Canter, 1987; Podraza & Darley, 1977). Our study offers a framework for understanding these inconsistencies by suggesting that cueing effectiveness is dependent upon the locus of the patient's deficit. According to our dual mechanism account, "lexical selection" patients would be expected to be more responsive to the provision of word-initial phonology than



“phonological encoding” patients. Indeed, the phonological priming paradigm may prove to be a useful variant of the traditional phonemic cueing technique that will enable researchers to more extensively manipulate the kinds of phonological cues provided during word production, and in so doing, learn more about how cues operate to facilitate the word production process.

#### 7.4. Conclusion

Existing evidence about word production comes from studies of both normal and aphasic performance. However, while studies of normals have included both descriptive errors analyses and experimental investigations, studies of aphasics have so far been largely descriptive—most have involved qualitative analyses of spontaneously produced errors. There have been relatively few attempts to manipulate aphasic production within an experimental setting. The present paper attempts to fill this gap by manipulating aphasic word production within a priming paradigm. The results obtained contrast dramatically with recent findings from normals, by demonstrating that phonological primes can have different effects on production depending upon the position of the shared phonemes and the nature of the aphasic person’s impairment. The findings provide new information about the processes at the two hypothesised stages of word production, particularly those involved at the phonological encoding stage. They also offer new insight into the phonological priming paradigm itself, by suggesting that phonological primes can potentially operate at different stages of processing. The model of the priming task developed here may provide a useful framework for interpreting the results of future priming studies involving both normal and aphasic subjects.

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## Appendix A. Experimental items

### 1. Items used in Experiment 1—Patient IG

Figures in parentheses indicate primes that shared more than (plus signs) or less than (minus signs) one syllable with the target

Target	Unrelated prime	Structure prime	Begin-related prime	End-related prime
acorn	jungle	almond	able	popcorn
antler	comic	inkwell	anthill	muffler
apron	lettuce	oblong	apex (+ 1)	matron (– 1)
barrel	kidney	collar	ballet	quarrel
button	daisy	pickle	buggy	threaten
camel	gipsy	dinner	candy	normal
cannon	shepherd	possum	captive	linen
chimney	dagger	sundae	chicken (– 1)	brownie
cradle	panic	pleasing	crazy	noodle
diaper	uncle	table	diet	creeper
engine	steeple	omelette	envy	surgeon
funnel	challenge	dollar	furrow	journal
giraffe	lesson	belong	Japan	carafe
ladder	stencil	rebel	Latin	glider
leopard	peanut	modest	letter	pampered
lobster	kitten	pamphlet	lobby	plaster
magnet	spinach	victim	magnum (+ 1)	planet
mushroom	cargo	deadline	muscle	bridegroom
needle	llama	major	neon	bridle
onion	treacle	oblong	under	jigsaw
peacock	current	totem	pizza	shamrock
penguin	sugar	tantrum	pendant (– 1)	sequin (– 1)
pillow	budget	cashew	pimple	swallow
pumpkin	illness	victim	puncture	napkin
saddle	burglar	figure	Saturn	idol
seesaw	dozen	cocoa	jigsaw	seagull
spider	toffee	frozen	spicy	thunder
ticket	ulcer	rapid	tissue	bracket
tractor	ribbon	Stetson	tracksuit	rooster
windmill	palace	textbook	Winter	sawmill
zipper	minstrel	bottle	zigzag	snapper
balcony	conductor	gondola	balancing	company
cigarette	factory	parasol	signature (+ 1)	clarinet (– 1)
computer	prejudice	disgraces	companion (+ 1)	spectator
dominoes	handicap	tolerate	dominate (+ 3)	buffaloes (– 1)

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## Appendix (continued)

Target	Unrelated prime	Structure prime	Begin-related prime	End-related prime
elephant	monitor	additive	elderly	occupant (− 1)
envelope	staggering	absolute	enterprise	antelope (+ 1)
eskimo	quarantine	occupy	escalate (+ 1)	dynamo
furniture	entertain	pentagon	fertilise	temperature
microscope	century	basketball	mindlessness	periscope
propeller	Mexican	specific	proposal (+ 1)	distiller
pyramid	stereo	delegate	pitiful	invalid (+ 1)
saxophone	professor	hypnotise	sacrifice	monotone (− 1)
skeleton	applicant	clinical	skeptical	puritan
stethoscope	candidate	prosecute	sterilise	horoscope
submarine	innocent	dignified	subdivide	tangerine
tambourine	exercise	misbehave	Tanzania (− 1)	figurine
telescope	document	camouflage	telegram (+ 2)	horoscope
typewriter	disbelieve	housekeeping	timetable (− 1)	bullfighter (+ 1)
woodpecker	committee	baptism	woodworking	nutcracker

## 2. Items used in Experiment 1—Patient GL

Figures in parentheses indicate primes that shared more than (plus signs) or less than (minus signs) one syllable with the target

Target	Unrelated prime	Structure prime	Begin-related prime	End-related prime
anchor	taxi	angel	angry	poker
engine	steeple	omelette	envy	surgeon
antler	comic	inkwell	anthill	muffler
apron	lettuce	oblong	apex (+ 1)	matron (− 1)
chimney	dagger	sundae	chicken (− 1)	brownie
coffee	bucket	tissue	copper	trophy
dragon	riddle	blossom	drastic	jargon
barrel	kidney	collar	ballet	quarrel
castle	dolphin	buffer	caddie	bristle
feather	auction	shovel	ferry	brother
giraffe	lesson	belong	Japan	carafe
camel	gypsy	dinner	canvas	normal
carrot	master	pollen	candy	pirate
island	metal	August	icon	garland
ladder	stencil	rebel	Latin	glider
lobster	kitten	pamphlet	lobby	plaster
magnet	spinach	victim	magnum	planet
medal	oyster	rubber	mellow	cradle

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## Appendix (continued)

Target	Unrelated prime	Structure prime	Begin-related prime	End-related prime
mirror	cauldron	lemon	mini	error
monkey	nickel	limbo	mongrel	jockey
needle	llama	major	neon	bridle
rabbit	ankle	gossip	rally	sherbet
raccoon	thunder	bazaar	ravine	tycoon
rainbow	cactus	weekly	ranger	elbow
saddle	burglar	figure	Saturn	idol
scissors	meadow	balance	symbol	tweezers
shadow	knuckle	buggy	shatter	window
slipper	hiccup	freckle	slingshot	pepper
tractor	ribbon	stetson	tracksuit	rooster
trumpet	paper	spindle	truffle (– 1)	carpet
turtle	mango	falcon	turkey	beetle
windmill	palace	textbook	Winter (– 1)	sawmill
zipper	minstrel	bottle	zigzag	snapper
cannon	shepherd	possum	captive	linen
funnel	challenge	dollar	furrow	journal
leopard	peanut	modest	letter	pampered
pillow	budget	cashew	pimple	swallow
peacock	current	totem	pizza	shamrock (– 1)
penguin	sugar	tantrum	pendant (– 1)	sequin (– 1)
mountain	stomach	chamber	mouthful (– 1)	captain

## 3. Targets used in Experiment 2

Patient IG				
bacon		bagel	barber	bubble
bullet		candle	cherry	chicken
cigar		circle	circus	collar
cookie		doughnut	easel	garlic
label		lemon	letter	lettuce
lizard		medal	muzzle	olive
pedal		pencil	pirate	pocket
puppet		razor	robot	rocket
ruler		sailor	salad	sauna
sausage		soldier	table	wallet
Patient GL				
bacon		bagel	barber	bubble
bullet		cactus	candle	candy

(continued on next page)

## Appendix (continued)

cherry	chicken	circle	circus
collar	doughnut	genie	jockey
label	lemon	letter	lettuce
medal	muzzle	napkin	pedal
pencil	pirate	pocket	poison
razor	rocket	ruler	sailor
shoulder	shower	soldier	table
thimble	toilet	wagon	wallet

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