Journal of Experimental Psychology:
Human Perception and Performance
1997, Vol. 23, No. 4, 1217–1231

0096-1523/97/$3.00

Frequency and Consistency Effects in a Pure Surface Dyslexic Patient

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Data are presented from a neurological patient (M. P.) with an acquired deficit for naming words with atypical spelling–sound correspondences. In Experiment 1, the degree of consistency within neighborhoods of orthographically similar words had a parallel impact on M. P.'s pronunciations of regular and irregular words and nonwords. This result is more compatible with models in which the same basic procedure, sensitive in a graded fashion to both frequency and consistency, computes pronunciations for all types of letter strings than it is with models postulating separate lexical and nonlexical mechanisms. In Experiment 2, both correct and regularized pronunciations of exception words yielded response times significantly modulated by word frequency, a finding not predicted by any current model. Neuropsychological observations provide an important additional source of evidence regarding models of cognitive function.

The acquired disorder of reading known as surface dyslexia (following Marshall & Newcombe, 1973) presents dramatic testimony to the impact of the predictability of a word's pronunciation from its spelling pattern. When "pure" surface dyslexic patients are invited to read aloud words with typical spelling–sound correspondences (in English, words such as *mint*, *toad*, or *profile*), their performance may be well within the range of that of normal adult readers on measures of both accuracy and speed, especially if the patients are compared with age- and education-matched controls rather than with young university-educated students. Likewise, the patients' accuracy and speed in pronouncing orthographically legal nonword strings (*rint* or *froad*) may be indistinguishable from those of matched controls. In marked contrast to regular words and nonwords, words with atypical spelling–sound correspondences (e.g., *pint*, *broad*, or *island*) yield substantially subnormal accuracy, and the patients' errors in response to such words most often reflect the assignment of more typical correspondences, with *pint* named as if it rhymed with *mint*, *broad* pronounced like *road*, and the first syllable of *island* pronounced *is*. The impairment on irregular words is strongly modulated by word frequency: Accuracy on common irregular words like *have* or *done*, though usually reduced in comparison with that of normal readers, may be relatively good, but the error rate is markedly higher on less frequent words like *soot* or *gauge*.

A dozen or more investigations of this relatively pure form of surface dyslexia have been reported in the literature in the last decade (e.g., Behrmann & Bub, 1992; Bub, Cancelliere, & Kertesz, 1985; Funnell, 1996; McCarthy & Warrington, 1986; Parkin, 1993; Patterson & Hodges, 1992; Shallice, Warrington, & McCarthy, 1983). The disorder has also been labeled "Type I" surface dyslexia (Shallice & McCarthy, 1985) in order to contrast it with "Type II" surface dyslexia, in which patients show a significant regularity effect but are also detectably impaired in accuracy on nonwords and even on familiar words with typical spelling–sound correspondences.

Owing to the clarity of this pattern of impaired reading, pure surface dyslexia has attracted attention from researchers trying to understand the functional architecture of the cognitive system responsible for reading. If performance on regular words and nonwords is normal, then some component or components of the patient's reading system must be intact, and we might be able to learn something of relevance to models of normal reading about the operation of these subcomponents. Similarly, if exception word reading is markedly abnormal, then the operation of some component of the reading system must clearly have been disrupted, and thus surface dyslexia might inform us about the way in which various subcomponents must interact to produce a normal pattern of reading. Perhaps not surprisingly, however, there is currently little consensus on the implications of surface dyslexia for models of normal reading. To set the stage for our experimental investigations, we begin with a brief description of two classes of theory, or two frame-

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We are grateful to David Plaut for his major contributions to this work, especially, but not only, the simulation results reported in Table 2; to Jay McClelland and Mark Seidenberg for their substantial assistance to us in thinking about the issues raised by these results; and to Max Coltheart for helping us to clarify predictions of the dual-route cascaded (DRC) model and for providing us with the DRC model's "opinions" on the classification of the stimulus items in Experiment 1.

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works, concerned with modeling the process of reading aloud.

The theory of reading developed by Coltheart (1985; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart & Rastle, 1994), along with similar views held by many other authors (e.g., Baluch & Besner, 1991; Bernstein & Carr, 1996; Funnell, 1983; Herdman & Beckett, 1996; Paap & Noel, 1991), suggests that normal readers can compute the pronunciation of a written word in several independent ways. This view is known as the *dual-route model* of reading because even though it admits three different procedures, the third one is not thought to make a substantial contribution:

1. The written word makes contact with its stored representation in an orthographic input lexicon of familiar words from which the word's phonological representation in a speech output lexicon can be directly addressed. This procedure (called the *lexical* procedure) should in principle achieve a correct response for any familiar word, independent of its spelling–sound characteristics, but cannot produce a response to novel words.

2. The written word is parsed into orthographic subword constituents that are translated by rule into their most standard phonological equivalents; these phonological segments are then concatenated to produce a whole-string response. Operating in isolation, this procedure (called the *nonlexical*, or *sublexical*, procedure) will produce correct responses for words that have typical print–sound correspondences, correct (in the sense of typical) responses to nonwords, and incorrect responses to words that deviate from regular correspondences. Different versions of the dual-route model make different assumptions about the variety and size of orthographic–phonological constituents handled by the nonlexical route. In the version that will be discussed here—the computational dual-route cascaded (DRC) model of Coltheart et al. (1993)—the nonlexical route operates only on single graphemes and phonemes, linked by grapheme–phoneme correspondence (GPC) rules that are trained by exposure to the spellings of real words paired with their pronunciations. Some examples of proposals that do not limit sublexical phonology to GPC rules can be found in the work of Besner and Smith (1992), Kay and Bishop (1987), Norris (1994), and Patterson and Morton (1985).

3. The written word activates a semantic representation that is then translated into a pronunciation by way of processes normally used in object naming and spontaneous speech. This procedure will be insensitive to spelling–sound characteristics of the word but might be expected to favor words with rich, well-specified meanings such as concrete, imageable words. This *lexical-semantic* procedure, though clearly implicated in the acquired reading disorder known as deep dyslexia (Coltheart, Patterson, & Marshall, 1980; Plaut & Shallice, 1993), is not thought to play much of a role, if any, in the normal assignment of pronunciations to written words.

The interpretation of surface dyslexia in this framework is that "the nonlexical procedure remains entirely intact whereas the lexical procedure has been damaged in such a way that it can only deal fully successfully with very high-frequency words" (Coltheart, 1985, p. 13). Exactly which component of the lexical procedure is considered to be damaged—orthographic representations, phonological representations, or the procedure of activating one from the other—may be open to debate, though most studies of surface dyslexia have been interpreted as indicating loss of orthographic word representations (Behrmann & Bub, 1992).

An alternative theory of reading developed by Seidenberg and McClelland (1989) and Plaut, McClelland, Seidenberg, and Patterson (1996), along with similar proposals by Kawamoto and Zemblidge (1992) and Van Orden and Goldinger (1994), might be dubbed the *triangle model*. As originally depicted in the article by Seidenberg and McClelland (1989) and subsequently in many of its offspring articles, lexical processing is viewed as an interactive triangle of orthographic, phonological, and semantic representations. The translation of orthography to phonology, rather than consisting of separate lexical and nonlexical procedures, is viewed as a network that computes the pronunciation of any letter string: whether it is a familiar or a novel word and, if familiar, whether it is a high- or low-frequency word and whether it embodies typical or atypical spelling–sound correspondences. Words varying on these dimensions of frequency and consistency are, however, processed with different degrees of efficiency owing to various features of the network, including its distributed representations, connectivity, and the learning algorithm used. Processing of a high-frequency word like *have* can be reasonably accurate and efficient even though its pronunciation is atypical of other orthographically similar words because its frequency of occurrence in training produced a major impact on setting the weights on connections in the computation. Processing of a low-frequency word like *dole* can be reasonably accurate and efficient, despite its slight impact on the net, because its pronunciation agrees with that of most other similar words (*sole*, *hole*, *dome*). Lower frequency words with atypical or inconsistent spelling–sound correspondences, like *pint*, benefit from neither of these sources of efficiency and so tend to be slower, more error prone, or both when normal readers name such words aloud (e.g., Jared, McRae, & Seidenberg, 1990; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Taraban & McClelland, 1987).

The triangle model also proposes a second source of input to, or (to use the term and concept of Kawamoto & Zemblidge, 1992) source of constraint on, the pronunciation of written words: word meaning. The idea is that on the basis of only orthographic constraints, the reader's success in deriving correct pronunciations for low-frequency irregular words like *pint* may never become completely secure owing to pressure from conflicting words like *mint*, *hint*, *pink*, and so forth. If the network produces activation of both the vowel /aɪ/ (which is correct for *pint*) and the vowel /ɪ/ (as in *mint* and the majority of other words with similar orthographic patterns), then the fact that the semantic representation of the word casts its vote for /paɪnt/ rather than /pɪnt/ may explain why the correct pronunciation usually wins for the normal reader.

The interpretation of pure surface dyslexia in this framework is that the reading disorder is consequent upon loss of input from the semantic system, which reveals the weakness of the unaided orthography-to-phonology computation specifically for lower frequency words with an atypical spelling–sound relationship (see Plaut et al., 1996, and Patterson et al., 1996, for further development of this interpretation). This hypothesis accounts for the significant concordance, observed in several surface dyslexic patients (Funnell, 1996; Graham, Hodges, & Patterson, 1994; Hillis & Caramazza, 1991), between the particular irregular words that the patient fails to comprehend and those that he or she misreads. At a more general level, the hypothesis fits the fact that most reported cases of pure surface dyslexia have involved a central deficit of semantic memory and that all reported cases of surface dyslexia have involved anomia, which suggests a problem in the activation of phonology by the semantic system even if the semantic system is not itself disrupted (e.g., Graham, Patterson, & Hodges, 1995; Watt, Jokel, & Behrmann, 1997).

A third, *multiple levels*, theory of reading developed by Shallice and his colleagues (Shallice et al., 1983; Shallice & McCarthy, 1985; see also Cipolotti & Warrington, 1995, McCarthy & Warrington, 1986, and Norris, 1994) has some features in common with each of the first two frameworks. A single, complex procedure translates from orthography to phonology on the basis of correspondences of various sizes, including graphemes, subsyllables, syllables, and whole words; in this regard, the theory resembles the triangle model described above. The level of whole-word correspondences between spelling and pronunciation, however, is considered to have separate status, rather like the lexical route in dual-route models. Because the first two frameworks provide the sharpest distinction, our discussion is cast in terms of differing predictions from these two models.

We present some evidence regarding these issues from the reading performance of a surface dyslexic patient, M. P. Because this patient has been thoroughly described in several earlier communications (Behrmann & Bub, 1992; Bub et al., 1985; Bub, Black, Hampson, & Kertesz, 1988; Plaut, Behrmann, Patterson, & McClelland, 1993), we summarize her case history and previous investigations only briefly.

Case Report and Summary of Previous Investigations of M. P.

M. P., a right-handed woman, was hit by a motor vehicle in April 1979; she was 59 years old at the time. A CT scan taken 20 days after M. P.'s accident was subsequently summarized by Vanier and Caplan (1985) as "hypodensity mainly localized in the cortex and white matter of the middle temporal gyrus. Some extension to the superior temporal gyrus is possible" (p. 513). According to Bub et al. (1988), the hemorrhagic contusion resulting from the injury involved much of the left temporal lobe and extended into both subcortical and parietal regions. Neuropsychological evaluations 18 months posttrauma revealed normal performance on perceptual tasks such as block design and figure copying and reasonable nonverbal intelligence (26/37 on Raven's Coloured Progressive Matrices, 65th percentile for her age). By contrast, all tasks involving language comprehension or production yielded extremely poor performance. M. P.'s spontaneous speech was fluent but empty, with marked word-finding difficulty, verbal paraphasias, and jargon. She was profoundly anomic and showed no benefit from phonemic cues. Standard language comprehension tests, whether of single words or of sentences and for either spoken or written presentation, produced performance at or near chance levels. For example, on each trial of the word–picture matching test from the PALPA (Psycholinguistic Assessment of Language Performance in Aphasia; Kay, Lesser, & Coltheart, 1992), one of five pictures of relatively common objects must be selected to match a single spoken object name: M. P. scored 12/40, not significantly above chance, and her erroneous choices comprised eight close semantic distractors, seven more distant semantic distractors, five visual foils, seven unrelated foils, and one refusal to respond. Detailed experimental investigations of her comprehension by Bub et al. (1988) demonstrated that she accessed some residual semantic information from pictures of objects and that her comprehension of words was severely impaired, though she achieved above-chance performance in sorting words on the basis of their superordinate category (e.g., animals vs. clothing).

Two previous studies have reported on M. P.'s reading abilities. The investigation of M. P. by Bub et al. (1985) provided the first dramatic demonstration in the literature of the marked impact of word frequency on the exception-word deficit in surface alexia. Behrmann and Bub (1992) replicated these striking frequency effects and, on the basis of detailed comparisons of M. P.'s reading and writing and also a version of the word-superiority paradigm, interpreted M. P.'s deficit in written word processing as loss of representations from an orthographic lexicon used in both reading and writing.

Experiment 1: Neighborhood Consistency

Background, Predictions, and Stimuli

Both the dual-route and the triangle frameworks can account for surface dyslexic patients' likelihood to err on an irregular word like *soot*; but in the dual-route model, this problem arises from the fact that *soot* breaks the GPC rule *oo* → /u/, whereas in the triangle model it derives from the inconsistency between *soot* and other similarly spelled words such as *hoot* and *soon*. The theories therefore differ in their predictions about the expected impact, on the reading of surface dyslexics, of the degree of pronunciation consistency within an orthographic neighborhood. We shall (with one exception: see the discussion of *w* words below) define consistency in the traditional manner (since Glushko, 1979), which is in terms of the body or rime of a monosyllabic word, that is, vowel plus terminal consonant(s). This aspect of words is known to have a particular impact on the accuracy and speed of translating orthography to phonology (Kay & Bishop, 1987; Treiman, Mullennix, Bijeljac-Babic

& Richmond-Welty, 1995), though it is certainly not the only relevant aspect of consistency (see Plaut et al., 1996, for discussion).

A few more words about the issue of consistency should help to delineate the predictions of the two frameworks contrasted here and their broader implications for models of normal reading. According to dual-route theory, the critical distinction in the domain of spelling–sound correspondences is between regular and irregular words: Regular words are those whose pronunciations are correctly generated by the nonlexical rule system; all other words are irregular. At least as a first approximation (though see below), this dichotomy applies in an all-or-none, not a graded, fashion; thus the rule-regular word *spook* should be essentially impervious to the many orthographic neighbors that disagree with its pronunciation, and the disadvantage accruing to the rule-irregular word *hook* should not be alleviated by the fact that many orthographic neighbors share its phonology nor by the fact that some of these are frequently encountered words like *look* and *book*. According to the triangle model, by contrast, the critical variable in the domain of spelling–sound correspondences is not a dichotomy but rather—as initially proposed by Glushko (1979)—a continuum involving the consistency with which orthographically similar words take compatible or discrepant pronunciations. In an empirical and theoretical analysis of consistency effects, Jared et al. (1990) concluded that the size of the consistency effect for a target word is best captured by the summed frequency of its friends (words resembling the target both orthographically and phonologically) and its enemies (orthographically similar words with discrepant pronunciations). As detailed by Plaut et al. (1996) in the context of a connectionist model of the translation from print to pronunciation, processing in this kind of quasi-regular system will always be sensitive in a graded fashion to both consistency and frequency; and consistency should affect words that are regular as well as those exceptional by GPC rule.

The reason for our qualification above on the assertion that dual-route theories treat regularity in an all-or-none fashion is that the recent DRC model of Coltheart et al. (1993) does allow for some impact of consistency. Its lexical system, described as a version of the interactive activation model of McClelland and Rumelhart (1981), is expected to produce partial activation of words orthographically similar to the target word. Because the model operates in a cascaded fashion, and because there is also interactive activation between the phonological lexicon and the phoneme output system, partial activation of the phonologically friendly neighbors *look* and *book* could in principle facilitate naming of an irregular word like *hook*. By the same principle, partial activation of the phonologically unfriendly neighbor *said* could delay correct pronunciation of a regular inconsistent word (or nonword) like *paid* (*zaid*). Coltheart et al. (1993, p. 605) did not, however, commit themselves on the likely importance of such putative effects, nor on the extent to which consistency effects will be apparent in actual pronunciation outcomes as well as response latencies. Despite the tempering of the strict regularity dichotomy in this recent version of dual-route theory, therefore, a demonstration of significant consistency effects on the nature of pronunciations generated is still a stronger prediction from a triangle than a dual-route framework.

To our knowledge, no studies of surface alexic patients have specifically assessed performance on words and nonwords as a function of body-level neighborhood consistency. The investigation that comes closest is that of Shallice et al. (1983), who demonstrated a "levels of regularity" effect in the patient H. T. R.; but their stimulus materials differed from those in the experiment to be presented here in several ways. First, their manipulation concerned exclusively irregular words: "Mildly irregular" words were defined as those with a single phoneme that was not the most common for that grapheme (according to Wijk, 1966) but was not especially exceptional either (e.g., *dread*); "very irregular" words (e.g., *gauge*) contained either multiple irregularities or genuinely exceptional correspondences. In its consideration of the degree of irregularity, the study of Shallice et al. is similar in spirit to what we propose here; but we shall also be assessing whether performance on both regular words and nonwords is sensitive to consistency. Second, Shallice et al. selected a heterogeneous set of words with a variety of irregularities, including many multisyllabic words, and with many orthographically unusual items (e.g., *chaos, colonel, lieutenant*) in the "very irregular" condition; the manipulation of monosyllabic body consistency in our list, by contrast, is more specific and narrowly defined.

The set of stimulus items in this experiment consisted of quartets of monosyllabic letter strings matched for body and assigned to one of three consistency conditions on the basis of the ratio of the number of words in a specified orthographic neighborhood that have a regular spelling–sound relationship to the number of words in that neighborhood that have an exceptional spelling–sound relationship. Each body-matched quartet comprised a word regular (REG) by GPC rule (e.g., *hoot*), a word exceptional (EXC) by GPC rule (e.g., *soot*), and two nonwords (NON; e.g., *goot* and *noot*). The stimulus items are listed in the Appendix, and their characteristics are described in Table 1. In Consistency Condition 1, for each of the 24 quartets, the number of words with that body taking a regular pronunciation substantially outweighs the number with an exceptional pronunciation; the ratio of the two means is shown in Table 1. In Consistency Condition 2, consisting of 30 quartets, the ratio of REG:EXC words in the body neighborhood is much more balanced; in some instances, the ratio is still slightly in favor of regular pronunciation, but in others, words with an exceptional pronunciation outweigh the number of regular exemplars. Note that two different values are given for the mean number of EXC words; this is because in each consistency condition, there were several bodies (four in Condition 1, seven in Condition 2) with more than one irregular pronunciation. For example, the body *-ove* has eight regular words (e.g., *grove*), four exceptional words with the pronunciation as in *love*, and two more exceptional words pronounced as in *move*. The first value given in Table 1 for the mean number of EXC words in the REG:EXC ratio is the mean number of all EXC pronunciations for the word

Table 1
Characteristics of the Stimulus List for Experiment 1

Characteristic	Consistency Condition 1 (REG > EXC)	Consistency Condition 2 (REG ≤ EXC)	Consistency Condition 3 (*w* words)
No. of quartets	24	30	12
REG:EXC ratio in body neighborhood	9.9:1.6 (1.3)	3.6:4.6 (4.2)	[6.7:1.4]
REG:EXC ratio in *wa–wo* neighborhood[a]			2.0:14.5 (13.0)
Mean frequency of target words			
EXC	528.9	159.0	127.3
REG	75.1	93.7	102.2
Sample target items			
EXC words	pint	post	warm
REG words	hint	cost	farm
NON words	rint	fost	larm

Note. REG = regular; EXC = exceptional; REG:EXC = ratio of mean number of REG words to mean number of EXC words. Because there could be more than one irregular pronunciation of a given word body, two values are given for the mean number of EXC words in the REG:EXC ratios. The first is the mean number of all EXC words; the one in parentheses is the mean number of EXC words sharing the pronunciation appropriate to the particular EXC target word in the experiment. The brackets around the REG:EXC ratio in the body neighborhood for Consistency Condition 3 indicate that this body neighborhood ratio is not really germane to performance on *w* words.
[a] Excluding words ending in silent *e* like *wave* and *woke*.

bodies in that condition; the second value, in parentheses, is the mean number sharing the pronunciation appropriate to the particular EXC target word used in this experiment.

We included a final set of 12 quartets in this experiment, those in Consistency Condition 3, to enable a glance at another aspect of consistency effects. An inspection of experimental lists manipulating regularity (e.g., Paap & Noel, 1991; Taraban & McClelland, 1987) reveals that many of these contain a rather large proportion of words in the irregular or exception set that begin *wa-* or *wo-* (e.g., *warm, wash, word, worse*). These words are irregular by GPC rule[1]; but like many forms of irregularity in quasi-regular systems (see Seidenberg, 1992, for discussion), the *w* words in fact constitute a kind of subregularity. Venezky (1970) referred to this as the "W influence." Thus, although the pronunciation of *o* appropriate to *work* would indeed be highly atypical following most onsets in this kind of monosyllabic word (cf. *stork, form, north,* etc.), it is not in the least atypical in *w* words (*work, worm, worth,* etc.); and the same applies to *wa-*. In Table 1, the ratio of REG:EXC words in the body neighborhood is listed for the *w* words, but in brackets because this body-level information is not especially germane to performance on the *w* words. Instead, the relevant statistic is the number of words beginning *wa-* or *wo-* and having a pronunciation that is regular by GPC rule (as in *wax* or *worn*) relative to the number that break the GPC rule but obey the *w* subregularity (as in *wand* or *worm*). This ratio, listed only for the *w* set on the line below the body ratio in Table 1, is based on all of the monosyllabic words in the *Concise Oxford Dictionary* (Sykes, 1976) that begin *wa-* or *wo-* except those like *wave* and *woke* for which the pronunciation of the vowel is signaled by the final *e*. In fact, although the ratio would not favor irregular pronunciations of *w* words quite so strongly if these final-*e* words were counted, there would still be more words considered irregular than regular by GPC rule even with these included. As with the number of EXC words in the body neighborhoods, the two values for EXC words in the *w* neighborhood reflect (a) all exceptional pronunciations and (b), in parentheses, those exceptional pronunciations specifically in accord with the target item.[2]

What are the predictions of the two theoretical frameworks for M. P.'s reading performance in this experiment manipulating neighborhood consistency? According to the dual-route model, because (a) the regular words in all three conditions obey the rules, (b) the irregular words in all

[1] There are 15 examples in the Coltheart et al. (1993) GPC system in which context sensitivity requires special rules, such as the conditioning of the vowel *a* by postvocalic *r* (as in *harm*; cf. *ham*); in principle, therefore, *w* words presumably could be allowed special rules.

[2] In view of the claim that it is onsets plus vowels rather than body-level neighborhood characteristics that are relevant to the *w* words, the reader might wonder why the regular words and nonwords chosen as part of the *w*-word quartets shared their bodies with the EXC word rather than beginning *wa-* or *wo-*. The answer is simple: There are not enough appropriate lexical items to do this experiment. Excluding both final-*e* words like *wave* and *woke* and the two derogatory slang words *wog* and *wop*, the *Concise Oxford Dictionary* (Sykes, 1976) lists a total of two monosyllabic *wa-* words with a regular pronunciation (*wag, wax*) and the same number for *wo-* (*worn, wow*).

conditions break the rules, and (c) nonwords are assigned pronunciations by rule, M. P. should show a significant impairment on EXC words relative to REG and NON words in all three consistency conditions. According to the triangle model, on the other hand, performance on EXC words should be markedly worse than performance on the other two word classes in Condition 1 but should be at much less of a disadvantage in Conditions 2 and 3. For Conditions 1 and 2, which have the same (body-level) definition of consistency, the triangle model makes the following more specific prediction: If performance is assessed not as the proportion of correct pronunciations but rather as the proportion of regular pronunciations, M. P.'s performance on REG, EXC, and NON words should be affected in a parallel fashion by consistency condition. That is, she should produce more regular pronunciations in response to items in Condition 1 than to items in Condition 2, whether the words are regular, exceptional, or unfamiliar.

The mean word frequencies for the six sets of real words are listed in Table 1. Given the selection constraints imposed by the neighborhood characteristics, especially for bodies with just one regular or irregular exemplar, it was impossible to achieve a good match between the frequencies of the REG and EXC words in each of the three consistency conditions. Note, however, that the frequency differences go against the triangle model's predicted impact on M. P.'s performance. That is, the mean frequencies of the EXC words decline across the three consistency conditions, whereas M. P.'s performance on these words, relative to REG and NON words, is predicted to improve across the three conditions.

For normal readers, the pronunciation assigned to a word or nonword with more than one legitimate body pronunciation can be influenced by the occurrence of orthographically similar words in the list of stimulus items (Kay & Marcel, 1981; Seidenberg et al., 1984; Stanhope & Parkin, 1987). We did not know whether M. P. would also be subject to this kind of influence; given that she might be, however, we ensured that each of the three main blocks of stimuli, comprising a mixture of REG, EXC, and NON words, contained only one item with each body: That is, *pint* was allocated to one block, *hint* to another, and *rint* to the third. Because the list contained only one regular and one irregular word for each body, this separation across blocks should have been sufficient to guard against cross-talk effects. Because the result of interest for nonwords was the proportion of regular:irregular pronunciations, however, we added an additional, separate block of pure nonwords that should not be subject to any "lexical" biases from within the stimulus set; this is why each body was represented by two nonword exemplars.

Method

The letter strings were presented to M. P., each preceded by a 1-s fixation point, on the screen of a Macintosh Plus; the words and nonwords were in lowercase black print on a white background. M. P. was instructed to read each letter string as it appeared, but no time pressure was enforced and response times (RTs) were not measured. There was an intertrial interval of 2 s following each response. As indicated above, the items were divided into four blocks: The first three of these were mixed blocks of REG words, EXC words, and NON words, with equal numbers of each type of stimulus in each block and with each of the three items sharing a body (e.g., *pint, mint, rint*) assigned to a separate block. The fourth block was composed exclusively of nonwords. M. P.'s pronunciation of each item was hand-recorded by the experimenter during the test session and also tape-recorded for later checking.

Results and Discussion

Overall accuracy. Table 2 shows M. P.'s percentages of correct responses to REG and EXC words, and percentages of regular pronunciations to nonwords, for each of the three consistency conditions. Because her performance on the nonwords from pure and mixed blocks was identical, the single value given for nonwords in each of the three conditions represents the average of the mixed and pure blocks.

In one sense, the obvious question to pose of these results would be whether M. P.'s performance on items within a

Table 2
Performance on the Stimulus Items in Experiment 1 by M. P. and by the Network in Plaut, McClelland, Seidenberg, and Patterson (1996, Simulation 4) When the Strength of the Semantic Contribution to Phonological Output Units Has Been Reduced to 0.2

Word type	Consistency Condition 1 (REG > EXC)	Consistency Condition 2 (REG ≤ EXC)	Consistency Condition 3 (*w* words)
	M. P.		
EXC words (% correct)	38	57	75
REG words (% correct)	100	83	83
NON words (% regular)	90	78	67
	Lesioned network		
EXC words (% correct)	29	63	83
REG words (% correct)	96	83	100
NON words (% regular)	92	63	100

Note. REG = regular; EXC = exceptional.

word class (EXC, REG, or NON words) varied significantly across the three consistency conditions (REG > EXC, REG ≤ EXC, *w* words). This analysis, however, would involve comparisons across different numbers of items in the three conditions, with especially small numbers in the third condition. It would also, in comparing *pint* with *post* rather than *pint* with *mint*, fail to take account of the body matching across word classes. Instead, therefore, we asked a different statistical question of the data: Did M. P.'s performance on items within a condition (REG > EXC, REG ≤ EXC, or *w* words) vary significantly across the three word types (EXC, REG, and NON words)? This is a rather tougher test of consistency effects because, in a severe surface alexic patient like M. P., one might always expect to observe a significant deficit on EXC words. The answer to this question, analyzed with the chi-square statistic, is that there was a highly reliable difference between word types for Condition 1, χ^2 (2) = 27.4, $p < .001$; a borderline difference for Condition 2, χ^2 (2) = 5.7, p = .056; and no significant difference in Condition 3, χ^2 (2) = 0.89, p = .64. That is, M. P.'s accuracy in reading EXC words was at a substantial disadvantage, relative to her accuracy in reading REG and NON words, for body neighborhoods like *-int* and *-ave* in which the majority of words sharing a body have the same, consistent, regular pronunciation of the vowel. Her accuracy on EXC words from body sets like *-ost* and *-ead*, in which words with the irregular vowel pronunciation according to the GPC rule are not in fact exceptional for that body neighborhood, was somewhat poorer than for matched REG and NON words, but only marginally so. When a rule-irregular pronunciation of the vowel *a* or *o* was strongly conditioned by an initial *w*, M. P.'s accuracy in reading so-called irregular words was not reliably different from her success on REG and NON words.

Although it is not our intent, in this article, to attempt to provide a detailed fit between M. P.'s performance and a simulation of surface dyslexia, it seems helpful to demonstrate that a computational model with the processing principles for which we have argued would yield a similar pattern of performance. For this purpose, in Table 2 we present results for the materials of Experiment 1 from one particular "lesioned" stage of Simulation 4 in the work of Plaut et al. (1996). As explained in our introduction, the triangle framework suggests that pure surface dyslexia arises from loss of the normal semantic constraints on phonological activation. Plaut et al.'s Simulation 4 was therefore trained (on approximately 3,000 monosyllabic English words) not only with orthographic input to the phonological output units but also with a gradually increasing additional source of input intended to mimic semantic constraints. At the end of training, the network produced (a) essentially perfect accuracy in naming words in the training set and (b) pronunciations of nonwords well within the range of real normal readers' nonword naming. After training of this network with both orthographic and semantic input to phonology, some or all of the semantic input can be withdrawn so that the network serves as an analogue of patients with pure surface dyslexia, most of whom suffer from degraded semantic representations. Simulations with this kind of "lesion," therefore, reveal the underlying adequacy of the orthography-to-phonology computation in a system that originally learned to rely on semantic as well as orthographic constraints. Table 2 shows the network's performance on the items from Experiment 1 when nearly but not quite all semantic input has been withdrawn, as seems appropriate for matching M. P.'s severely impoverished semantic abilities. The performance of the network at this stage is strikingly similar to M. P.'s performance. The most notable discrepancies are between the patient's and the network's success on the REG and NON words in Condition 3; as noted below in the analysis of M. P.'s errors, her responses to a number of items in these two groups were rather anomalous. All of the network's errors to EXC words were regularizations.

Errors. Almost all of M. P.'s errors to EXC words were regularizations (e.g., *pint* pronounced like *mint*, *put* like *hut*, and *break* like *speak*); her two nonregularization errors were *both* → "buth" (the vowel in *but*) and *shoe* → "shoo-uh" (i.e., with the final *e* pronounced as a schwa; interestingly, her responses to the two nonword strings from the *-oe* neighborhood were *broe* → "broa-uh" and *voe* → "voa-uh"). Almost all of her errors to REG words involved pronunciation of the body in accord with its pronunciation in one or more EXC words from that body neighborhood, for example, *font* to rhyme with *front*, *grove* like *love*, *case* like *phase*. She did however read *bough* → "bauf"; this is just about the only plausible pronunciation of *-ough* that is not represented by a word from this highly inconsistent neighborhood. Most of her nonregular pronunciations of nonwords, like her errors on REG words, were legitimate, irregular body pronunciations (e.g., *lon* → "lun" as in *son*, *fove* → "fuv" as in *love*, and *pook* to rhyme with *book* rather than *spook*).

The errors on the REG and NON word strings in the *w*-word set require comment. With a single exception (the nonword *dorth*, which she pronounced to rhyme with *worth*), every one of the 10 nonregular pronunciations was in response to a word or nonword with the spelling pattern consonant–*ar*–(consonant) as in *cart*, *sar*, or *marn*, and in every case the vowel in M. P.'s response was an *r*-conditioned tense *a* vowel as in the word *care*. This is not an easy sound to produce when it is followed by a terminal consonant as in *cart* or *larp*, but that is how M. P. responded to all of these items. In a sense, this makes her correct pronunciations of the *w* words *war*, *warp*, *warn*, and *warm* even more impressive.

Further analysis of Conditions 1 and 2. As indicated in the description of expected outcomes for this experiment, the triangle framework's emphasis on consistency effects leads to the following prediction: If performance is measured not as the percentage of correct pronunciations, but as the percentage of regular pronunciations, then the change in the ratio of REG:EXC words from Consistency Condition 1 to Consistency Condition 2 might be expected to have a similar impact on performance for all types of letter strings—REG, EXC, or NON words. The results of this analysis, shown in Figure 1, support that prediction. EXC

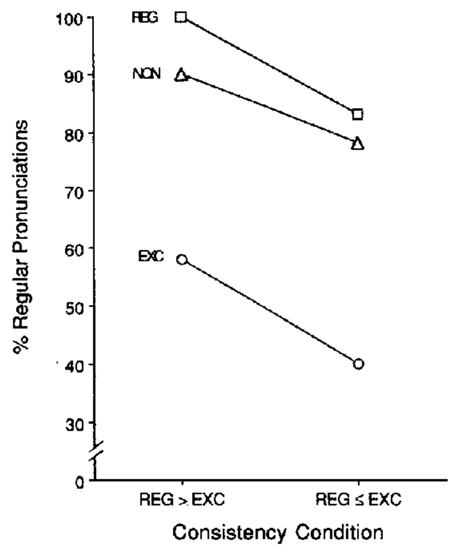

Figure 1. M. P.'s performance on regular (REG), exceptional (EXC), and nonword (NON) items from Consistency Conditions 1 (REG > EXC) and 2 (REG ≤ EXC) of Experiment 1, analyzed not as the percentage of correct pronunciations but as the percentage of regular responses.

words, of course, engendered substantially fewer regular pronunciations overall, because M. P. was still able to read a number of exception words correctly; but the shift in balance from REG > EXC to REG ≤ EXC in body neighborhood had strikingly parallel effects for all three types of letter strings on M. P.'s likelihood of assigning a regular pronunciation. We conclude from these results that M. P.'s surface alexia cannot be adequately characterized as a rule-governed assignment of GPC correspondences but rather is sensitive to graded aspects of consistency.

Experiment 2: The Time Course of Word Naming in Surface Dyslexia

Background and Predictions

In studies of word naming by normal readers, the standard dependent variable is RT for correct responses to various types of words. The usual finding, in too many studies to list, is a frequency-by-regularity interaction, with significantly slowed RTs only to words that are both relatively low in frequency and atypical in spelling–sound correspondence. Error rate is often negligible, though in fact it can be as high as 10–12% for low-frequency exception words (e.g., Glushko, 1979). In studies of word naming by surface dyslexic patients, the standard dependent variable is accuracy for various types of words. When RTs have been measured, the goal has usually been to demonstrate that the patient's speed is within or near the normal range and that therefore the patient is plausibly reading by some subset of normal procedures rather than by some abnormal compensatory mechanism (see, e.g., McCarthy & Warrington, 1986; Patterson & Hodges, 1992; Shallice et al., 1983). Patients' word-naming RTs have rarely if ever been used to address theoretical issues.

The scant attention paid to word-naming latencies in surface dyslexia is perhaps not surprising. First, many of the lower frequency exception words that yield slow RTs for normal readers would be removed from a patient's RT analysis because these words engender errors; it is therefore not clear that the data would include enough correct RT responses to produce a reliable frequency-by-regularity interaction. Second, even with enough observations to support such an analysis, the failure to obtain a normal pattern of RTs in a single patient may not be interesting or interpretable. The majority of significant RT effects in normal performance are shown by group means but not necessarily by every reader in the group, and it has recently been established that only about half of individual normal readers produce the characteristic frequency-by-regularity RT interaction (Bernstein & Carr, 1996). One cannot therefore be confident that a specific patient would, premorbidly, have shown the effect in question. Finally, patients with serious brain disease or injury often have deficits in addition to the one under scrutiny; their performance on attention-demanding tasks like speeded word naming may fall outside the normal range or may fail to demonstrate clean patterns because of these additional factors.

With all of those caveats in mind, latency analyses in pure surface alexia may nonetheless be illuminating. One question that might be posed of such data concerns the time course of correct and regularized pronunciations to exception words. Few studies of normal readers have reported error RTs, presumably because the number of errors is typically too small to make such measures meaningful. It is intriguing, however, that in the rare reports focusing on regularization errors by normal readers, responses like *pint* → /pɪnt/ have sometimes been as fast as, if not faster than, correct readings of these lower frequency exception words (e.g., Kawamoto & Zemblidge, 1992; Patterson & Morton, 1985; see also Van Orden & Goldinger, 1994). Both dual-route and triangle frameworks can account for such observations. In the DRC model (Coltheart et al., 1993; Coltheart & Rastle, 1994), activation at the phoneme level rises gradually as a result of input from both lexical and nonlexical routes, with overlapping distributions of time to reach a criterial level for responding. Because the rise time in activation for the lexical route is modulated by word frequency, the nonlexical route may occasionally reach criterion for a lower frequency word before lexical activation arrives and (in the case of an exception word) conflicts with it. In the triangle framework, a word like *pint* activates phoneme output units for both the vowels /aɪ/ (correct) and /ɪ/ (incorrect, but much more typical in such an orthographic context). In recurrent net versions of this kind of model, there may be a period in the settling process where the correct and regularized pronunciations have similar levels of activation; and in stochastic versions with some degree of indeterminacy of outcome, the regularization error might occasionally be produced with a relatively rapid RT.

Predictions from these frameworks regarding RTs for correct and error responses by a surface dyslexic patient are not entirely obvious, partly because one does not know the extent of the putatively reduced contribution of the lexical route or additional semantic input to phonology. The following might therefore be described as speculations rather than firm predictions. Both models presumably expect that, given enough observations and the assumption of a premorbid frequency-by-regularity interaction in RTs, the patient would continue to produce this "normal" RT pattern for correct responses. What pattern might be expected for regularization errors in response to exception words? In a dual-route model, in which regularization errors are computed by the nonlexical GPC route that activates neither orthographic nor phonological word forms nor the lexical pathway between them, either there should be no frequency effect on regularization RTs or errors in response to high-frequency words should be associated with longer RTs than should errors in response to less common exception words. Suppose that the damaged lexical route is still producing some degree of phonological activation, even though—in the case of a regularization error—this has clearly not been sufficient to win out over the GPC route's response. Such lexical activation might be expected to occur earlier, more strongly, or both and therefore to produce more interference with the error response from the GPC route, for high-frequency words. In the triangle model, one would presumably expect no frequency effect on RTs for errors because the time course of these responses should reflect the network's knowledge about the regular exemplars (*hint*, *mint*, *print*, etc.) rather than the regularized target word (*pint*).

Despite the fact that these predictions are tentative and do not necessarily differentiate strongly between models, we present data on M. P.'s time course of word naming because there are virtually no such data in the literature and also because the results were surprising.

Method

The word list used to investigate M. P.'s speed of word naming consisted of high-, medium- and low-frequency REG and EXC words (see Patterson & Hodges, 1992, for details of the list). It contained 252 words, half REG and half EXC, matched pairwise for frequency, length, and (important when measuring RTs) initial phoneme. Naming of these words by normal elderly readers (Patterson, Graham, & Hodges, 1994) produced a low error rate (1% or less for all frequency bands of REG words and for the high- and medium-frequency EXC words; 5% for the low-frequency EXC items) and RTs showing significant effects of both frequency and regularity and an interaction between them.

M. P. was asked to read the words from this list, presented one at a time, in three blocks separated by brief rest intervals, with each block containing an equal number of REG and EXC words. The equipment and procedure were identical to those in Experiment 1 except that RTs were measured by microphone and voice key.

Results and Discussion

Table 3 shows both accuracy and RT data for M. P. for the six conditions of Experiment 2. The accuracy data, revealing a dramatic frequency-by-regularity interaction, are not "news": They merely replicate the effect demonstrated by both Bub et al. (1985) and Behrmann and Bub (1992) for M. P. in reading other lists of words varying on these two dimensions. Before we turn to the RT data, however, we should comment on one feature of M. P.'s correct and error responses. As in Experiment 1 and in other studies of M. P.'s reading, nearly all of her errors to EXC words were regularizations; but in both Experiments 1 and 2, there were some EXC words to which M. P. either made a regularization error immediately followed by a self-correction or—more intriguing—a correct response immediately followed by a "self-uncorrection," that is, a change from a correct response to a regularization error. Furthermore, there were equal numbers of these two "directions" of changed responses: across the two experiments, seven of each.

This aspect of reading in a surface alexic patient has been commented on by Funnell (1996): E. P., the patient in that study, produced an even greater number of self-corrections and self-uncorrections than did M. P. but, like M. P., in about equal proportions. Of particular interest to Funnell was E. P.'s tendency, on occasions when she changed a correct response to a regularization error, to explain and justify her final choice of response on the basis of its "logic"—for example, in response to the word *subtle*, she first regularized it, then read it correctly, and finally said, "It's got a B in it so it must be sub-tel." This kind of sophisticated reasoning, or at least its verbal expression, was far beyond M. P.'s capability; but apart from the justifications offered by E. P., the 2 patients exhibited the same behavior in frequently creating two alternative pronunciations of an EXC word. Funnell's interpretation of this phe-

Table 3
M. P.'s Performance in Experiment 2: Accuracy and Mean Response Times (in Milliseconds)

Word frequency	% correct		Correct responses to REG words			Correct responses to EXC words			Regularized pronunciations to EXC words		
	REG	EXC	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*
High	95	79	36	725.0	82.1	32	772.9	111.1	8	797.0	134.0
Medium	95	52	39	859.3	230.3	22	851.4	129.0	19	849.5	113.7
Low	88	45	34	878.7	143.2	17	870.2	164.1	17	883.5	144.2

Note. REG = regular; EXC = exceptional.

nomenon, in a dual-route framework, was that the correct responses are generated by the lexical route and the regularization errors are generated by the nonlexical route. Our interpretation is that the same procedure computes both pronunciations and that, in the absence of any information from other parts of the system, particularly word meaning, the patient has no real basis for preferring either. Although nothing in the existing data permit one to choose between these two interpretations, we suggest that our account is at least given some plausibility by the following fact: The computational models implemented by Plaut and McClelland (1993) and Plaut et al. (1996) sometimes yield similar levels of activation of both the correct and regularized pronunciations for low-frequency inconsistent words. This is relatively easy to observe because, in the phonological representations of these networks, individual output units correspond to phonemes at different positions of the monosyllabic word (onsets, vowels, codas). For most exception words (e.g., *pint*), the correct and regularized pronunciations differ by a single phoneme, typically the vowel; and one can assess the strength of the model's "opinions" about the two candidate pronunciations by examining activation levels for the output units corresponding to /aɪ/ and /ɪ/ when the network computes the pronunciation of *pint*.

We turn now to M. P.'s RT data. First, considering only correct responses to REG and EXC words,[3] a 2 (word type: REG or EXC) by 3 (frequency band: high, medium, or low) analysis of variance (ANOVA) produced a significant main effect of frequency, $F(2, 174) = 11.61$, $p < .001$, but neither a main effect of regularity nor a significant interaction (both Fs < 1). The RT equivalence between M. P.'s correct responses to lower frequency EXC and REG words may be partly due to the fact that many of the low-frequency EXC words, which yield correct but slow responses in normal readers, elicited errors for M. P. and are thus excluded from the correct RT analysis. In general, however, the absence of a frequency-by-regularity interaction for naming times is presumably attributable to the fact that M. P. showed a substantial frequency effect on REG-word RTs.

This effect, already demonstrated (though not commented on) in the first study of M. P.'s reading (Bub et al., 1985), is rather surprising, because normal readers' RTs to regular words typically yield a small-sized impact of frequency (e.g., Waters & Seidenberg, 1985). In an attempt to understand the cause or causes of this effect, we performed a regression analysis of M. P.'s response times to REG words in which the following factors were included: (a) frequency (absolute value from Kučera & Francis, 1967); (b) length—although REG and EXC words in this list are matched pairwise for length across all frequency bands, there is a slight confounding between frequency and length (for REG words, the mean word lengths for high-, medium- and low-frequency bands, respectively, are 4.1, 4.6, and 4.8 letters); and (c) five measures of orthographic "wordlikeness"—(1) Coltheart's *N*-count, that is, the number of words that can be produced from any letter string by changing a single letter; (2) summed bigram frequency; (3) summed trigram frequency; (4) position-specific summed bigram frequency; and (5) position-specific summed trigram frequency. A three-variable model provided the best fit to M. P.'s RT data, accounting for 23% of the variance: *N*-count (15%), *N* plus position-specific trigram frequency (19%), and those two plus frequency (23%). A similar analysis on correct RTs to both REG and EXC words yielded significant effects only of length and frequency, accounting for 24% of the variance and suggesting that the strong impact of the wordlikeness variables (*N* and trigram frequency) is selective to REG words. It is not obvious why M. P.'s speed of naming of REG words should be subject to a greater-than-normal impact of orthographic wordlikeness. Behrmann and Bub (1992), in a whole-string report version of the word-superiority paradigm, demonstrated that M. P.'s accuracy of report showed an abnormal sensitivity to the frequency of (mainly regular) words, but they concluded that orthographic factors like *N* could not account for this result.

Even more surprising is the comparison between RTs for correct and regularized responses to EXC words. As Table 3 shows, except for the highest frequency band of words, there were virtually identical numbers of responses in these two response classes; and also as can be seen in Table 3, M. P.'s mean RT was essentially identical for the two types of response to EXC words. A two-way ANOVA confirmed that there was a main effect of frequency on both correct and regularized responses, $F(2, 218) = 4.89$, $p < .001$, but no hint of a reliable difference between the two response classes nor of an interaction between frequency and response type (both Fs < 1). As far as we can see, this equivalent frequency effect on M. P.'s correct and regularized responses to EXC words would not be predicted by any current model of the reading process. In a dual-route model, the nonlexical route operating in isolation should be insensitive to word frequency. Alternatively, if the lexical route was producing sufficient activation to delay (though not to supplant) responses based on nonlexical activation, then one might anticipate slower regularization RTs to high- than to low-frequency EXC words. In a triangle model, the processing that leads to a regularization error will still be influenced to some degree by characteristics (such as frequency) of the target word itself but should presumably be governed mainly by characteristics of the regular enemies in the target word's neighborhood.

We tentatively suggest that the effect may be arising prior to the processes of spelling–sound translation, in the perceptual–orthographic analysis of letter strings. As already mentioned, Behrmann and Bub (1992) demonstrated a dramatic sensitivity to word frequency in M. P.'s written whole-word report following pattern-masked presentation

[3] Note that the numbers of correct responses (*N*) beside the mean RTs for each condition in Table 3, if divided by the total number of items per condition (42), would not yield the percentage correct figures on the left in the table. This is because, as for normal readers only perhaps more so, a certain number of M. P.'s correct naming responses had to be excluded from the RT analysis either because they were outliers (>2 *SD*s) in the RT distribution for that condition or because of voice key failures.

of letter strings, in marked contrast to normal control readers' accuracy, which showed a word-superiority effect but no significant impact of word frequency. This result, among others, led Behrmann and Bub to their conclusion that M. P.'s reading deficit could be characterized as a frequency-modulated loss of representations from an orthographic lexicon. That conclusion does not fit easily with a framework like the Plaut et al. (1996) triangle model, in which orthographic (and other) representations are assumed to be distributed rather than local; but either kind of model might encompass a process of orthographic analysis that, in M. P., is abnormally sensitive both to the familiarity of the specific orthographic pattern (hence the word-frequency effect for the speed of both her correct and error responses to EXC words) and to the general wordlikeness of orthographic pattern (hence the significant impact of N and trigram frequency on her REG-word RTs).

General Discussion

The basic pattern of pure surface dyslexic reading—normal accuracy on both regular and novel words, coupled with a frequency-sensitive deficit on exception words in which the majority of errors reflect assignment of more typical subword correspondences—can be explained both by a dual-pathway conception of the process of translating letter strings from orthography to phonology (e.g., Coltheart et al., 1993) and by a framework emphasizing graded activations of distributed orthographic, phonological, and semantic representations of words (e.g. Plaut et al., 1996), often depicted as a triangle and thus here dubbed the triangle model of reading. To make progress in understanding surface alexia and its implications for theories of reading, therefore, we need observations that go beyond this basic pattern encompassed by both theories.

In the first experiment, we examined a surface dyslexic patient's reading responses to irregular words, regular words, and nonwords varying in consistency of pronunciation within orthographically similar neighborhoods of words. The size of M. P.'s exception-word deficit was significantly affected by this consistency manipulation. Even more dramatically, the proportion of M. P.'s regular responses to all three types of letter string declined in a parallel fashion as a function of a change from body neighborhoods like *-int* (with far more regular than irregular exemplars) to those like *-ove* (with more nearly equal numbers of regular and irregular exemplars). M. P.'s errors on regular words and her nonregular pronunciations of nonwords in the latter condition were almost all assignments of a common exceptional body-level pronunciation (such as *grove* → "gruv", pronounced like *love*). Because there are very few body neighborhoods in which the number of irregular types far outweighs the regular exemplars, we resorted to a manipulation of consistency at the beginnings of exception words in order to look at this end of the continuum. For exception words conforming to the subregularity of *wa-* (e.g., *warm*) or *wo-* (*worm*), M. P.'s reading accuracy revealed no reliable disadvantage relative to body-matched regular words and nonwords (e.g., *farm* and *larm*). These features of her performance on rule-irregular words cannot be explained by word frequency: Although the frequencies were not especially well matched across consistency conditions, the exception words had the highest mean frequency in Consistency Condition 1, which yielded the largest deficit, and the lowest mean frequency in Consistency Condition 3 (the *w* words), which produced no reliable exception-word disadvantage.

This pattern of results does not support a standard dual-route view of the reading process in which there are separate lexical and nonlexical reading pathways. It is not yet clear whether the results can be accommodated by the Coltheart et al. (1993) DRC model, which allows at least some room for consistency effects by virtue of cascaded processing and interactive activation between the phonological lexicon and the phoneme system activated directly by GPC rules. The parallel effect of consistency on regular words, exception words, and nonwords is, however, a straightforward prediction from the similarity-based connectionist accounts proposed by Plaut et al. (1996), Seidenberg and McClelland (1989), and Van Orden and Goldinger (1994); and indeed the network developed by Plaut et al. (1996) as a simulation of surface dyslexia, when lesioned and tested on the stimulus list from Experiment 1, produced a pattern of performance similar to M. P.'s. In this framework, apparent rule-like behavior emerges from the fact that the most common correspondences—because they are represented in the largest number of words and thus are experienced more often—have more influence on learning and processing. The system will be sensitive to degree of consistency at any level or "size" of unit. For example, the pronunciation of *work*, though inconsistent with its body neighbors like *cork*, is highly consistent with its onset plus vowel neighborhood. Bodies have no special status conferring undue influence on degree of consistency at the body level. Body-level consistency is so predictive of reading performance simply because the reader learns, correctly, that the body is often a useful level of generalization. When, as in *wo-* words, a more useful statistical clue comes from the beginning rather than the end of the word, both human and computer reading systems learn that, too. M. P. (and several other surface dyslexic patients we have tested who also show this *w* effect; see Patterson et al., 1996) clearly had learned this generalization.

In Experiment 2, we examined M. P.'s word-reading RTs. The fact that her responses to medium- and low-frequency exception words include virtually identical numbers of correct and regularized responses provides a rare opportunity to examine the time course of correct and erroneous outcomes in a situation in which the estimate of RTs associated with errors is likely to be as stable as that for correct responses. The surprising result of this analysis was equivalent mean RTs, lengthening in an identical fashion as a function of decreasing word frequency, for correct and regularized responses to exception words. Neither of the frameworks contrasted here would have predicted this pattern. Although we have assumed M. P.'s reading to be abnormal primarily in the ability to compute phonological and semantic representations from orthographic input, this unexpected result may suggest an abnormally slow and frequency-sensitive rise time on activation of orthographic representations (see also Behrmann & Bub, 1992). This outcome does not alter the conclusions from Experiment 1 about the nature of the process for translating orthography to phonology. It remains to be seen whether the phenomenon is characteristic of other surface alexic patients: This study with M. P. of the time course of correct and incorrect word naming in surface alexia is, thus far, unique.

One final result of interest from both experiments is that, as well as producing virtually identical numbers of correct and regularized pronunciations to (different) exception words, M. P. sometimes produced both responses to a single target exception word (see Funnell, 1996, for a report of the same phenomenon in another surface dyslexic patient). M. P. was equally likely to begin with a regularization error and self-correct it (as she did for the word *are*) or to produce the correct response first and then change to the regularized pronunciation (as she did for the word *crow*). *Are* is a highly frequent word but is opposed by a large cohort of unfriendly neighbors (*care*, *fare*, *rare*, etc.); *crow* is a rather infrequent word, but its body neighborhood contains many exemplars of both alternative pronunciations (*flow* and *tow* vs. *brow* and *vow*). In cases such as these, we suggest that the network for computing pronunciations from spelling patterns tends to activate both pronunciations. In some instances, the two will have different strengths of activation based on the factors of word frequency and neighborhood consistency; but in cases where the activation levels of the two alternatives are roughly equivalent, there may be a degree of unpredictability as to which response will be emitted (or, if both, which one first). In the normal reader, the additional constraint on phonology provided by word meaning can help the network to settle on the appropriate pronunciation (Kawamoto & Zemblidge, 1992). A patient with a profound deficit of word meaning has lost this additional constraint.

This brings us to a final, brief comment on the putative relevance of M. P.'s semantic memory impairment. According to the dual-route framework, M. P.'s profound comprehension deficit and her severe surface alexia are unrelated deficits. The association is attributed to anatomical proximity of two unrelated brain systems, one devoted to word comprehension and another to lexical connections between orthography and phonology. In the triangle model, on the other hand, these two deficits are functionally related, because interaction with word meaning helps the reading system to achieve correct pronunciations for words that are processed inefficiently by the direct computation of phonology from orthography. The view that this is a meaningful association takes support from a number of observations. (a) Essentially all pure surface alexic patients reported in the literature have had either a central semantic deficit or at least an anomia suggesting reduced communication from meaning to phonology (Graham et al., 1995; Parkin, 1993; Watt et al., 1997). (b) Severity of the surface alexic pattern in at least one study correlated with the extent of the semantic or naming impairment (Patterson & Hodges, 1992). (c) In several cases, investigators have established a significant word-specific concordance between exception-word reading and comprehension (Funnell, 1996; Graham et al., 1994; Hillis & Caramazza, 1991). (d) Plaut et al. (1996) produced an impressive simulation of surface dyslexia by withdrawing the additional source of input to the phonological system that was designed to represent semantic constraints on phonology. (e) Normal readers show a much stronger impact of spelling–sound regularity for low-frequency words with abstract rather than concrete or imageable meanings (Strain, Patterson, & Seidenberg, 1995); because concrete words are thought to have richer, stronger semantic representations than do abstract words (Plaut & Shallice, 1993), this result again suggests that word meaning may contribute to written word naming, especially when the translation from spelling to sound is fragile.

Despite this accumulation of support, we acknowledge that the hypothesized meaningful relationship is still a working hypothesis that requires considerably more substantive evidence and that indeed has been questioned in several ways. For one thing, as acknowledged by Plaut et al. (1996) and emphasized by Bernstein and Carr (1996), the additional source of input to the phonological units in Simulation 4 of the Plaut et al. model was not a genuine representation of word meaning. Thus the conclusion that this important additional constraint is semantic in nature (rather than, say, lexical, as suggested by Bernstein & Carr, 1996, p. 89) may be premature. Furthermore, although there are, to our knowledge, no significant exceptions to the rule that severe, pure surface alexic patients have an associated semantic deficit or anomia, it has recently become clear that the entailment does not work perfectly in the other direction. Both Cipolotti and Warrington (1995) and Lambon-Ralph, Ellis, and Franklin (1995) have recently reported single-case studies of patients with poor comprehension of lower frequency words but normal reading of low-frequency exception words. Plaut et al. (1996) speculated that this dissociation, as well as the phenomenon of hyperlexia (Metsala & Siegel, 1992), may be explained by variation in the extent to which individual normal (or abnormal) developing readers learn to rely on support from word meaning. There are certainly strong indications that reading is a source of substantial individual differences in pattern as well as degree of skill (see Bernstein & Carr, 1996, for discussion). The pertinence of variations in normal pattern to the range of associations and dissociations observed in acquired disorders remains to be determined from future empirical and theoretical progress in the study of reading and its abnormalities.

In conclusion, the current study of a surface dyslexic patient was designed to expand our understanding of both the nature of this acquired reading disorder and its implications for conceptions of the normal reading system. The dual-route and triangle models contrasted here may constitute starkly opposing conceptions of reading or—especially as they continue to be elaborated—may begin to converge on some similar principles of processing. In either case, we argue that this kind of detailed analysis of neuropsychological data, in tandem with similar studies of normal reading, will inform theoretical development.

References

Baluch, B., & Besner, D. (1991). Visual word recognition: Evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory and Cognition, 17,* 644–652.

Behrmann, M., & Bub, D. (1992). Surface dyslexia and dysgraphia: Dual routes, single lexicon. *Cognitive Neuropsychology, 9,* 209–251.

Bernstein, S. E., & Carr, T. H. (1996). Dual-route theories of pronouncing printed words: What can be learned from concurrent task performance? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 86–116.

Besner, D., & Smith, M. (1992). Basic processes in reading: Is the orthographic depth hypothesis sinking? In R. Frost & L. Katz (Eds.), *Advances in psychology: Orthography, phonology, morphology, and meaning* (pp. 45–66). New York: North Holland.

Bub, D., Black, S., Hampson, E., & Kertesz, A. (1988). Semantic encoding of pictures and words: Some neuropsychological observations. *Cognitive Neuropsychology, 5,* 27–66.

Bub, D., Cancelliere, A., & Kertesz, A. (1985). Whole-word and analytic translation of spelling to sound in a nonsemantic reader. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 15–34). Hillsdale, NJ: Erlbaum.

Cipolotti, L., & Warrington, E. K. (1995). Semantic memory and reading abilities: A case report. *Journal of the International Neuropsychological Society, 1,* 104–110.

Coltheart, M. (1985). Cognitive neuropsychology and the study of reading. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 3–37). Hillsdale, NJ: Erlbaum.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100,* 589–608.

Coltheart, M., Patterson, K., & Marshall, J. C. (Eds.). (1980). *Deep dyslexia.* London: Routledge & Kegan Paul.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1197–1211.

Funnell, E. (1983). Phonological processing in reading: New evidence from acquired dyslexia. *British Journal of Psychology, 74,* 159–180.

Funnell, E. (1996). Response biases in oral reading: An account of the co-occurrence of surface dyslexia and semantic dementia. *Quarterly Journal of Experimental Psychology, 49A,* 417–446.

Glushko, R. J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 674–691.

Graham, K. S., Hodges, J. R., & Patterson, K. (1994). The relationship between comprehension and oral reading in progressive fluent aphasia. *Neuropsychologia, 32,* 299–316.

Graham, K. S., Patterson, K., & Hodges, J. R. (1995). Progressive pure anomia: Insufficient activation of phonology by meaning. *Neurocase, 1,* 25–38.

Herdman, C. M., & Beckett, B. L. (1996). Code-specific processes in word naming: Evidence supporting a dual-route model of word recognition. *Journal of Experimental Psychology: Human Perception and Performance,* 1149–1165.

Hillis, A. E., & Caramazza, A. (1991). Mechanisms for accessing lexical representations for output: Evidence from a category specific semantic deficit. *Brain and Language, 40,* 106–144.

Jared, D., McRae, K., & Seidenberg, M. S. (1990). The basis of consistency effects in word naming. *Journal of Memory and Language, 29,* 687–715.

Kawamoto, A. H., & Zemblidge, J. H. (1992). Pronunciation of homographs. *Journal of Memory and Language, 31,* 349–374.

Kay, J., & Bishop, D. (1987). Anatomical differences between nose, palm and foot, or, the body in question: Further dissection of the processes of sublexical spelling–sound translation. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 449–469). Hillsdale, NJ: Erlbaum.

Kay, J., Lesser, R., & Coltheart, M. (1992). *PALPA: Psycholinguistic assessment of language performance in aphasia.* London: Erlbaum.

Kay, J., & Marcel, A. J. (1981). One process, not two, in reading aloud: Lexical analogies do the work of nonlexical rules. *Quarterly Journal of Experimental Psychology, 33A,* 397–414.

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Lambon-Ralph, M. A., Ellis, A. W., & Franklin, S. (1995). Semantic loss without surface dyslexia. *Neurocase, 1,* 363–369.

Marshall, J. C., & Newcombe, F. (1973). Patterns of paralexia: A psycholinguistic approach. *Journal of Psycholinguistic Research, 2,* 175–199.

McCarthy, R., & Warrington, E. K. (1986). Phonological reading: Phenomena and paradoxes. *Cortex, 22,* 359–380.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88,* 375–407.

Metsala, J. L., & Siegel, L. S. (1992). Patterns of atypical reading development: Attributes and underlying reading processes. In S. J. Segalowitz & I. Rapin (Eds.), *Handbook of neuropsychology* (Vol. 7, pp. 187–210) Amsterdam: Elsevier Science.

Norris, D. (1994). A quantitative multiple-levels model of reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1212–1232.

Paap, K. R., & Noel, R. W. (1991). Dual route models of print to sound: Still a good horse race. *Psycholinguistic Research, 53,* 13–24.

Parkin, A. J. (1993). Progressive aphasia without dementia due to focal left temporo-frontal hypometabolism—A clinical and cognitive analysis. *Brain and Language, 44,* 201–220.

Patterson, K., Graham, N., & Hodges, J. R. (1994). Reading in dementia of the Alzheimer type: A preserved ability? *Neuropsychology, 8,* 395–407.

Patterson, K., & Hodges, J. R. (1992). Deterioration of word meaning: Implications for reading. *Neuropsychologia, 30,* 1025–1040.

Patterson, K., & Morton, J. (1985). From orthography to phonology: An attempt at an old interpretation. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 335–359). Hillsdale, NJ: Erlbaum.

Patterson, K., Plaut, D. C., McClelland, J. L., Seidenberg, M. S., Behrmann, M., & Hodges, J. R. (1996). Connections and disconnections: A connectionist account of surface dyslexia. In J. Reggia, R. Berndt, & E. Ruppin (Eds.), *Neural modeling of cognitive and brain disorders* (pp. 177–199). Singapore: World Scientific.

Plaut, D. C., Behrmann, M., Patterson, K., & McClelland, J. L. (1993). Impaired oral reading in surface dyslexia: Detailed comparison of a patient and a connectionist network [Abstract 540]. *Psychonomic Society Bulletin, 31,* 400.

Plaut, D. C., & McClelland, J. L. (1993). Generalization with componential attractors: Word and nonword reading in an attractor network. In *Proceedings of the 15th Annual Conference of the Cognitive Science Society* (pp. 824–829). Hillsdale, NJ: Erlbaum.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56–115.

Plaut, D. C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10,* 377–500.

Seidenberg, M. S. (1992). Connectionism without tears. In S. Davis (Ed.), *Connectionism: Advances in theory and practice* (pp. 84–137). Oxford, England: Oxford University Press.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behavior, 23,* 383–404.

Shallice, T., & McCarthy, R. (1985). Phonological reading: From patterns of impairment to possible procedures. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 361–398). Hillsdale, NJ: Erlbaum.

Shallice, T., Warrington, E. K., & McCarthy, R. (1983). Reading without semantics. *Quarterly Journal of Experimental Psychology, 35A,* 111–138.

Stanhope, N., & Parkin, A. J. (1987). Further exploration of the consistency effect in word and nonword pronunciation. *Memory & Cognition, 15,* 169–179.

Strain, E., Patterson, K., & Seidenberg, M. S. (1995). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1140–1154.

Sykes, J. B. (Ed.). (1976). *Concise Oxford dictionary of current English.* Oxford, England: Clarendon Press.

Taraban, R., & McClelland, J. L. (1987). Conspiracy effects in word recognition. *Journal of Memory and Language, 26,* 608–631.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124,* 107–136.

Vanier, M., & Caplan, D. (1985). CT scan correlates of surface dyslexia. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 511–525). Hillsdale, NJ: Erlbaum.

Van Orden, G. C., & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1269–1291.

Venezky, R. L. (1970). *The structure of English orthography.* The Hague, The Netherlands: Mouton.

Waters, G. S., & Seidenberg, M. S. (1985). Spelling–sound effects in reading: Time course and decision criteria. *Memory & Cognition, 13,* 557–572.

Watt, S., Jokel, R., & Behrmann, M. (1997). Surface dyslexia in non-fluent progressive aphasia. *Brain and Language, 56,* 211–233.

Wijk, A. (1966). *Rules of pronunciation for the English language.* Oxford, England: Oxford University Press.

Appendix

Stimulus List for Experiment 1

Consistency Condition 1 (REG > EXC)				Consistency Condition 2 (REG $\leq$ EXC)				Consistency Condition 3 (*w* words)			
EXC	REG	NON-1	NON-2	EXC	REG	NON-1	NON-2	EXC	REG	NON-1	NON-2
are	care	sare	vare	bear	fear	plear	trear	war	far	sar	dar
have	gave	mave	bave	deaf	leaf	neaf	heaf	wasp	clasp	masp	nasp
sew	dew	bew	rew	heard	beard	meard	keard	wash	crash	pash	fash
pint	hint	rint	nint	breath	sheath	feath	neath	watch	match	satch	gatch
shoe	toe	broe	voe	height	weight	seight	peight	warp	harp	narp	larp
wool	cool	nool	hool	sieve	grieve	rieve	tieve	warn	yarn	harn	marn
gross	cross	bross	foss	ninth	plinth	hinth	rinth	warm	farm	larm	darm
touch	couch	bouch	houch	wolf	golf	tolf	molf	work	fork	lork	dork
bowl	howl	powl	frowl	come	home	bome	pome	worm	form	borm	horm
put	cut	dut	lut	ton	yon	fon	lon	worth	north	dorth	gorth
aunt	haunt	baunt	maunt	monk	honk	lonk	sonk	swamp	cramp	gamp	famp
caste	baste	daste	naste	front	font	bont	hont	quart	cart	gart	nart
breast	beast	deast	reast	both	cloth	koth	toth				
flange	grange	nange	pange	youth	mouth	nouth	gouth				
broad	road	foad	doad	glove	grove	blove	fove				
break	speak	deak	neak	pour	sour	mour	bour				
give	five	pive	mive	vase	case	tase	dase				
foot	root	goot	noot	where	here	yere	bere				
bush	rush	nush	sush	post	cost	fost	bost				
bull	dull	tull	sull	soul	foul	loul	roul				
said	paid	gaid	haid	blown	crown	trown	pown				
great	beat	sneat	creat	good	food	bood	tood				
done	phone	glone	chone	wild	gild	hild	pild				
lose	nose	bose	cose	bread	plead	jead	kead				
				roll	doll	koll	holl				
				crow	vow	fow	gow				
				cough	bough	mough	lough				
				small	shall	nall	dall				
				brook	spook	pook	dook				
				sought	drought	hought	mought				

Note. REG = regular, EXC = exceptional, and NON = nonword. Although it is claimed in the text that every word classified here as REG is regular by grapheme–phoneme correspondence (GPC) rule and every word classified as EXC is irregular by GPC rule, there are in fact three cases that are open to question, one in Condition 1 and two in Condition 2:

1. *grange–flange*: The GPC component of the dual-route cascaded (DRC) model (Coltheart et al., 1993) considers *flange* regular and therefore *change*, *mange*, *range*, *grange*, and *strange* irregular. We could not locate a ruling on this specific spelling pattern in the work of Venezky (1970).
2. *sour–pour*: The GPC component of the DRC model has a rule for the letter string-*our* (because it corresponds to a single phoneme in both Australian and southern British English); according to this rule, *pour* is regular and *sour* irregular. By Venezky's analysis, on the other hand, the rule would apply to -*ou* rather than -*our*, and *sour* is the regular pronunciation, which accords with our classification.
3. *doll–roll*: Both the DRC model and Venezky dispute our assignment and consider *roll* to have the rule-governed pronunciation.

With so few uncertainties of assignment, which moreover are nearly evenly balanced between Conditions 1 and 2, our results should not need qualification on the grounds of these three questionable cases. We note also that M. P.'s performance in all of these cases matched our intuitions: That is, in each of these three pairs, she correctly read the former (which we considered "regular by rule") and pronounced the latter as if it rhymed with the former.

Received July 10, 1995
Revision received March 28, 1996
Accepted May 29, 1996 ■