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Spelling-to-sound effects in single-word reading

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Computational modelling of word-naming processes has suggested that the *frequency* of spelling-to-sound correspondence facilitates print-to-sound translation time and has given rise to predictions that are supported by empirical data (Brown, 1987*a*). This contrasts with earlier claims that *regularity* is the only spelling-to-sound correspondence attribute that determines word-naming time. Here we report further evidence for the effects of the frequency of spelling-to-sound correspondences on word-naming latency. Experiment 1 excludes alternative, orthographic neighbourhood interpretations of the putative spelling-to-sound effects. Experiment 2 shows that a word's number of rhymes does not affect naming latency for that word, thus excluding explanations in terms of output phonology. Experiment 3 replicates earlier findings that a word's spelling-to-sound enemies, as well as friends, determine naming latency. Thus both the regularity and the frequency of spelling-to-sound correspondences influence word-naming time. The implications for models of oral reading processes are explored.

When a printed word is read aloud, there are various ways in which pronunciation information may be derived. The most direct mechanism involves obtaining a phonological output from a stored lexical entry that is accessed from the visual form of the word. This mechanism alone is clearly insufficient, given that nonsense or unfamiliar words without existing lexical entries can also be read aloud by normal adults. A second possible mechanism is the construction of a pronunciation using stored spelling-to-sound rules that describe the most likely pronunciation of any letter string conforming to the spelling structure of the language. In English, however, where many words have irregular pronunciation (i.e. are pronounced differently to those with a similar spelling), the use of spelling-to-sound rules alone would be highly unreliable and produce many reading errors.

Traditional dual-route theories of word naming posit both lexical and rule-based procedures operating in parallel. Output phonology is either accessed from a stored lexical entry, or is constructed by means of spelling-to-sound correspondence rules. These rules can provide pronunciations when new or unfamiliar words are encountered. In dual-route models, the rule-based phonology is redundant when access to a high frequency word produces the lexical-based information faster and more reliably. However, when lexical access to lower frequency items takes longer, phonology from the rule-based routine may become available before pronunciation begins, and in the case of words with irregular spelling-to-sound correspondences

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this may slow the production of the word's sound. This interference type of account is universal among models of word naming and provides a possible explanation of the reported spelling-to-sound regularity or exception effects on naming time and their interaction with word frequency (Seidenberg, Waters, Barnes & Tanenhaus, 1984).

Another possible spelling-to-sound translation process involves a single system for words and non-words alike that refers by 'analogy' to the stored pronunciations of lexical items with similar spelling patterns (see Humphrey & Evett, 1985 for a review). Within this framework, all possible orthographic segments of the presented letter string are used to activate corresponding phonology within the lexical store. Lexical analogy theory has increasingly been viewed as a possible alternative to the dual-route hypothesis, and, whilst the underlying distinctions between the two approaches may be less concrete than they originally appeared (e.g. Norris & Brown, 1985; Patterson & Coltheart, 1987), there has been a shift in emphasis away from the notion of stored rules being used to assemble output phonology, even for non-word items.

Despite the evolution of the analogy and, more recently, 'multiple levels' models of oral reading (e.g. Shallice & McCarthy, 1985), there has until recently been little change in the type of empirical effect that these models seek to explain, or in the nature of the explanation that is invoked. Typically, the time taken to read spelling-to-sound regular words (e.g. PILL, whose orthographic neighbours, MILL, TILL, HILL, etc. are all pronounced similarly) is contrasted with the reliably longer latencies obtained for irregular or exceptional words such as PINT (cf. MINT, TINT, HINT, etc.). As described above, the effect is explained in terms of interference arising from the competing phonologies of differently pronounced orthographic neighbours that are activated by the related spelling patterns. In support of this, there has been little evidence for the effect of other spelling-to-sound attributes, and the nature of the apparent regularity effect (i.e. shorter latencies for words that have the prevalent or the only spelling-to-sound correspondence, compared with the slower naming of exceptional items) easily lends itself to an interference explanation.

However, whilst the empirical spelling-to-sound regularity effect and associated interference account have survived a change in emphasis from spelling-to-sound rules to lexical analogy, more recent computational modelling work has suggested possible alternative underlying determinants of word naming time and has provided a different perspective on the processes involved in translating print to sound. Connectionist models have questioned whether rules (such as spelling-to-sound correspondence rules) ever actually underlie cognitive processes. Characterizing the true nature of phonological effects on single-word reading is therefore important as it has implications for the architecture (connectionist or otherwise) that is most appropriate for modelling lexical processing.

In the development of one model, Brown (1987*a*, *b*, *c*) suggested that differences between spelling-to-sound correspondence patterns might be better characterized in terms of their *frequency* rather than their *regularity*, and that any such frequency effect might reflect the facilitative influence of regular spelling-to-sound mappings. He demonstrated that the spelling-to-sound frequency variable could be implemented in a computational word-naming model to produce frequency-based facilitation rather than regularity-based interference, and reported a pattern of effects on adult word-naming times that was predicted by the output of the connectionist model.

Brown's classification of words into those with common/consistent, exceptional and unique spelling-to-sound correspondences dissociated spelling-to-sound regularity and frequency, which he claimed are confounded in the conventional comparison of regular and irregular words. In the standard classification based on regularity, regular words tend to have frequently occurring spelling-to-sound correspondences whilst irregular words contain uncommon correspondences. Brown's classification contained three word types. 'Common/consistent' words (e.g. PILL) have spelling-to-sound correspondences that are both frequently encountered (cf. MILL, HILL, TILL, FILL, etc.) and regular (there are no words ending with the spelling -ILL that do not rhyme with PILL). Conversely, 'exception' words have correspondences that are both unique and irregular; for example, PINT is the only word in English with the terminal -INT spelling that does not rhyme with MINT, HINT, TINT, etc. However, in the third category, 'unique' words, frequency and regularity of spelling-to-sound correspondence are dissociated. Like exception words, they have unique spelling-to-sound correspondences, but like common/consistent words, they are also regular. This regularity is defined in terms of there being no exceptions to the prevalent spelling-to-sound relationship. For example, SOAP is the only word in English where the spelling -OAP gives the pronunciation/wp/, and so has a unique correspondence. However, SOAP is also the only word in the language with that particular terminal spelling pattern, and so, although low in frequency, its pronunciation is not exceptional. There is no spelling-to-sound mapping at the trigram level to which it is an exception.

The classification of words as 'regular' or 'irregular' is one that arises naturally from the assumption that spelling-to-sound translation rules are employed by subjects in these tasks. In terms of the analogy-like models we will be discussing henceforth, however, it is more natural to describe a word's spelling-to-sound characteristics in terms of its 'friends' (defined as the number of the word's orthographic neighbours, i.e. words with the same vowel and final consonant cluster that are pronounced in the way as, i.e. rhyme with, the word in question) and 'enemies' (defined as the number of the word's orthographic neighbours that do not rhyme with the word in question). Thus, in terms of the spelling-to-sound classification suggested by Brown (1987*a*), exception words such as PINT have many enemies (MINT, HINT, TINT, etc.) but no friends (there are no other -INT words that rhyme with PINT). Common/consistent words, such as PILL, in contrast, have only friends (HILL, MILL, TILL, etc.). There are no -ILL words that do not rhyme with PILL. Finally, unique words such as SOAP have neither friends nor enemies as they have no immediate orthographic neighbours. We will adopt this 'friends and enemies' terminology throughout the remainder of this paper. In common with other researchers in this field, we classify words in terms of the pronunciation of the vowel and terminal consonant cluster. There is considerable evidence that this is the relevant psychological unit (e.g. Treiman & Chafetz, 1987; Treiman & Zukowski, 1988).

It was therefore possible for Brown (1987*a*) to compare data from words that varied on frequency but not on regularity of spelling-to-sound correspondence (no friends, no enemies versus many friends, no enemies) and to compare words that varied on regularity but not on frequency (no friends, no enemies versus no friends, many enemies). As previous experiments had not accounted for this confound, their results could provide no information about whether frequency or regularity was the true determinant of naming time. However, in a word-naming experiment conducted with normal adults, Brown reported a significant independent effect of correspondence frequency (i.e. a friends effect) but found no evidence for a regularity (presence of enemies) influence.

In summary then, most theoretical accounts of print-to-sound translation suggest that pronunciation is slowed when the competing phonologies of inconsistent orthographic neighbours are activated. The recent and influential model of word naming developed by Seidenberg & McClelland (1989; see also Patterson, Seidenberg & McClelland, 1989) also make this prediction. This model is supported by the apparently robust exception word effect in which words with enemies take longer to read aloud than items without enemies. Brown (1987*a*) claimed that the number of friends rather than the number of enemies might underlie these latency differences and provided evidence to support the hypothesis that reading time is affected by the facilitative influence of friends rather than by interference from enemies.

The data reported by Brown (1987*a*) indicated that the friends effect was independent of the words' enemies, and that there was no effect of enemies when number of friends was held constant. However, Seidenberg & McClelland (1989) reported an experiment in which number of friends was controlled for and a residual effect of enemies on naming times was nevertheless obtained (see also Jared, McRae & Seidenberg, 1990). Naming latencies for regular consistent items (those with only friends) were compared with latencies for regular inconsistent words. Regular inconsistent items are those with both friends and at least one enemy. The consistent and inconsistent words were matched for Brown's spelling-to-sound frequency factor (the number and combined word frequency of the friends). Thus the consistent and inconsistent items had the same overall number of friends. Brown's facilitation model would predict that a consistent and an inconsistent word with the same number of friends would be read aloud at the same speed because they should receive equal facilitation from the friends and no interference should be caused by the enemy or exception word to the inconsistent items. Thus, for example, the inconsistent MINT (cf. PINT) should be pronounced as quickly as the consistent MILL. However, Seidenberg & McClelland (1989) reported that the inconsistent items were read significantly more slowly than the consistent words, suggesting that interference was operating.

The results reported by Brown (1987*a*) provided evidence for facilitation rather than interference processes on two counts. The first was that an effect of friends was obtained under conditions that were independent of number of enemies. The second was that no enemies effect emerged when friends were controlled for. However, there are potential problems with the interpretation of both aspects of the results.

This paper reports a series of experiments designed to resolve the question of whether or not there are independent spelling-to-sound friend and enemy effects on word naming time. Experiment 1 is concerned with the friends effect in the data reported by Brown (1987*a*), and by examining effects of friends and enemies under different upper/lower case conditions tests the possibility that the apparent effect of spelling-to-sound friends was due to an orthographic neighbourhood influence. Experiment 2 tests the possibility that the frequency with which sublexical phonological units are used in word production underlies apparent spelling-to-sound influences. Finally, Expt 3 attempts to replicate the spelling-to-sound consistency result reported in Seidenberg & McClelland (1989) and explores the nature of the effect obtained.

We now explain in more detail why orthographic neighbourhood factors could compromise the putatively phonological effects of spelling-to-sound friends on word-naming time. If orthographic neighbourhood size has an independent effect on word-naming time, it might have increased the apparent size of the friends effect. The friends effect was based on the observation that words with spelling-to-sound friends are named faster than words without. But as shown below, words with many friends will generally have larger orthographic neighbourhoods than friendless items, so either phonological or orthographic factors (or both) could be responsible for the latency differences.

Brown's friendless words such as SOAP necessarily have smaller orthographic neighbourhood sizes than either words with enemies only or words with many friends, because these words are, by definition, those with an orthographically unique final trigram (for four-letter words). Thus, whilst the materials used in Brown's (1987*a*) word-naming experiment were matched on positional *bigram* frequency, final trigram frequency would have been impossible to control for. Indeed, the differences between vowel/final consonant cluster spelling patterns form the basis of Brown's classification.

Thus, if the convention of considering only the terminal trigram of four-letter words is adopted, orthographic neighbourhood size can be seen to be perfectly confounded with both spelling-to-sound friends for no-enemy (unique and common/consistent) words and with spelling-to-sound enemies for words with no friends (unique and exception words). In the friends effect comparison, unique items have neither friends nor orthographic neighbours whilst common/consistent words have many friends and many neighbours. Similarly, in the enemies effect comparison, unique words have neither enemies nor orthographic neighbours whilst exception words have many of both. These comparisons may be clarified by reference to Table 1, which lists the spelling-to-sound and orthographic features of Brown's word types.

In order to evaluate the true severity of the difficulty caused by the confound, it would be useful to know to what extent the orthographic neighbourhoods for exception and common/consistent words are larger than the neighbourhoods of unique words. Orthographic neighbourhood size has previously been investigated using the measure known as 'Coltheart's N.' Coltheart's N for a word is the number of other words that can be made up by changing just one letter of the item in question. This orthographic measure is likely to correlate with the spelling-to-sound measures at issue. For example, words with many spelling-to-sound friends are likely to have a large number of orthographic neighbours, and hence a higher N value, than words with no friends or enemies. Examination of the words used by Brown

Table 1. Spelling-to-sound and orthographic characteristics of Brown's (1987*a*) word types

	Unique (no friends, no enemies)	Common (many friends, no enemies)	Exception (no friends, many enemies)
Enemies	0	0	Many
Friends	0	Many	0
Orthographic neighbours	0	Many	Many

(1987*a*) confirms this: the words with neither friends nor enemies have a Coltheart's *N* value of 1.86, while the figures are 3.24 for words with enemies and no friends, and 6.33 words with friends and no enemies. So apparent effects of spelling-to-sound friends could in fact be due to orthographic neighbourhood as defined by Coltheart's *N*.

Previous studies of *N* effects have produced mixed results. Coltheart, Davelaar, Jonasson & Besner (1977) found no effects of *N* on lexical decision time for words, while high-*N* non-words were relatively hard to reject. Andrews (1989) found facilitatory effects of *N* on both lexical decision time and naming time for low-frequency words (see also Scheerer, 1987), and Laxon, Coltheart & Keating (1988) found that children made fewer errors to high-*N* words in reading, spelling and lexical decision. McCann & Besner (1987) found that high-*N* non-words were named more rapidly than low-*N* items. However, Grainger, O'Regan, Jacobs & Segui (1989), looking at gaze duration and lexical decision time, found that the mere presence of orthographic neighbours *per se* was not important: rather, times were longer for words with at least one orthographic neighbour of higher frequency (note that this is an inhibitory rather than a facilitatory effect).

In conclusion, studies of orthographic neighbourhood effects in word naming, the task at issue here, have found some evidence for a facilitatory effect of orthographic neighbourhood size. Orthographic neighbourhood size will be confounded with the number of spelling-to-sound friends possessed by an item, so effects previously interpreted as spelling-to-sound correspondence effects could in fact be orthographic neighbourhood effects. Experiment 1 was designed to address this issue.

EXPERIMENT 1

The first experiment was designed to test the suggestion that the spelling-to-sound friends effect found by Brown (1987*a*) was due to the confounding factor of orthographic neighbourhood size. The experiment also addressed the possibility that an orthographic neighbourhood effect (giving a relative advantage to exception words like HAVE) had cancelled out an underlying effect of number of enemies (giving a relative advantage to unique words like SOAP) in the word-naming experiment reported by Brown (1987*a*). We refer to this as the 'cancelling hypothesis'. If a real effect of enemies was operating, the word SOAP, which has no enemies, would be named faster than the enemy-possessing word HAVE. However, the frequency with which spelling patterns occur in the language (i.e. the number of a word's orthographic neighbours counted with no reference to pronunciation) might well independently affect word-naming time. There could, therefore, be facilitation of HAVE based on its larger orthographic neighbourhood, which could cancel out any enemy-based disadvantage of HAVE relative to SOAP.

As described above, a major problem for the design of such an experiment was that two potentially antagonistic influences, namely spelling-to-sound characteristics and orthographic neighbourhood size, are highly correlated within the orthographic units (i.e. the terminal trigrams of four-letter words) over which the spelling-to-sound characteristics are defined. An attempt to overcome this difficulty was made using a procedure that could be assumed to affect orthographic and spelling-to-sound effects differentially, such that any genuinely phonological effect would be evident. This procedure, which involved presenting the stimuli in three different case conditions, was suggested by results reported by Parkin & Underwood (1983).

Parkin & Underwood's (1983) experiment was designed to examine the possibility that the normal spelling-to-sound regularity effect was caused partly by the purely visual–orthographic regularity or 'strangeness' of the irregular words. To do this, they varied orthographic regularity as well as spelling-to-sound regularity in a lexical decision experiment. Orthographically and spelling-to-sound irregular words were compared with words with regular spellings but irregular pronunciations, and with words with both regular spellings and pronunciations.

Words with frequently occurring letter sequences have, in normal lower-case presentation, more familiar visual characteristics than orthographically irregular words (e.g. YACHT), which have more unusual shapes. Parkin & Underwood's (1983) hypothesis was that the orthographic regularity might contribute to the apparent spelling-to-sound regularity effect due to the greater visual familiarity of the more frequent orthographic units under lower-case presentation. Thus they varied both orthographic and spelling-to-sound regularity and altered the visual familiarity of the orthographic segments by using an upper-/lower-case manipulation. Stimulus presentation in lower case provides more familiar visual information about the word and emphasizes the differences between orthographically regular and irregular items if it is assumed that orthographic effects can have their influence at least partly through the visual familiarity of lower case orthographic subsequences. Thus, the manipulation of orthographic regularity and spelling-to-sound regularity under varying case conditions was hypothesized to indicate the extent to which the spelling-to-sound regularity effect was orthographic in nature.

The results reported by Parkin & Underwood (1983) demonstrated that the spelling-to-sound regularity effect was independent of visual shape/orthographic effects. Firstly, the spelling-to-sound regularity effect was maintained with both upper and lower case stimuli. However, the effect of orthographic regularity was clearly vulnerable to case change and therefore visual in nature. The orthographically 'strange' words were responded to much more slowly in lower than in upper case, while the upper-case responses were as fast as those for non-strange words.

The evidence from Parkin & Underwood (1983) provided the basis for the design of the present study. Experiment 1 was essentially a replication of the word-naming study reported by Brown (1987*a*) except that subjects were assigned to one of three presentation case conditions. Brown's three word types were presented in either lower, upper or alternating case (where upper and lower case letters were alternated within each word). Lower case words were assumed to provide the most visual information and therefore to promote orthographic influences to the greatest extent, as suggested by the Parkin & Underwood results. Alternating case was assumed to provide orthographic information in an even less familiar visual form than upper-case presentation and hence to be the least likely to be associated with orthographic effects.

The possibility discussed above was that the friends effect reported in Brown (1987*a*) was magnified by orthographic neighbourhood effects, because high-friend words have larger orthographic neighbourhoods than low-friend words when both have no enemies. If this is so, the friends effect should be abolished or reduced in the less familiar case presentations, because the lower-case presentation will favour orthographic effects relative to phonological ones.

For similar reasons, it was assumed that if the cancelling explanation of Brown's negative result regarding number of enemies was correct, the variation in case presentation would yield differential apparent spelling-to-sound effects over the three case conditions. If lower-case presentation facilitates orthographic effects, and if an orthographic effect cancels out the spelling-to-sound enemies effect, then an enemies effect should not emerge, or at least should be smaller, with lower case stimuli. On the other hand, upper- and/or alternating-case conditions were expected to inhibit any orthographic influences that might otherwise counteract the spelling-to-sound effect, and so under these conditions any genuine enemies effect could be expected to remain. Thus, evidence against the cancelling hypothesis was predicted to take the form of a non-significant interaction between spelling-to-sound effects and the effects of the case manipulation. On the basis of Brown's (1987*a*) results, interpreted as genuinely phonological rather than orthographic effects, uniformly non-significant enemy effects over the three case conditions would be expected.

Method

Subjects

Seventy-two students from University College of North Wales, Bangor took part in individual word-naming sessions. All were native English speakers, had normal or corrected-to-normal vision and normal reading skills. They were not paid for their participation. Twenty-four subjects were allocated to each of the upper, lower and alternating case of presentation conditions.

Materials

The verbal materials described and listed in Brown (1987*a*) were used as experimental stimuli. They comprised 63 words in the form of 21 matched triplets, with each triplet composed of a unique (e.g. SOAP), a common/consistent (e.g. PILL) and an exception (e.g. PINT) word. Items within triplets were matched as closely as possible on word length, initial phoneme, word frequency (Kucera & Francis, 1967) and positional bigram frequency (Solso & Juel, 1980). All words in the set had relatively low word-frequency values and different final vowel/consonant clusters. The 15 practice words used at the start of the procedure also had different spelling patterns.

Apparatus and procedure

An Apple Macintosh Plus microcomputer coupled to a microphone and voice key was used to present the stimulus words and to record reading latencies. The program used for experimental control was written in Microsoft BASIC. Response times were measured to an accuracy of 16.625 ms (1 'tick').

Each subject was seated in a room with normal illumination facing the 9 inch black and white microcomputer screen and the microphone, and given instructions and practice with the procedure. On each word-naming trial the sequence of events was as follows. A prompt message ('READY?') appeared in the centre of the screen until the subject made a key press that replaced the message with the stimulus word. The appearance of the stimulus word activated the timer which continued until the voice key was activated by the subject's voice. The stimulus word disappeared immediately and was replaced by the next 'READY?' prompt.

Subjects were not aware of the difference between the initial 15 practice trials and the experimental trials. The main body of the experiment was run as a single block of trials. The subjects were instructed to read the word aloud as quickly as possible, to speak clearly, to sit in the same position close to the microphone, and not to make incidental noises. Reading errors, hesitations, voice key failures and accidental voice key activations were recorded by the experimenter.

Results

Naming times were averaged for each word type–case condition and are shown in Table 2. Response time (RT) values were discarded prior to the analysis if the word had been mispronounced or if there was no valid response time measure because of voice key failure, accidental activation or response hesitation. For each response discarded, the RTs from that subject for the corresponding items in the other two conditions were also discarded. Thus, only the matched word triplets that were associated with three correct reading responses and three corresponding valid RT values remained for inclusion in the RT analyses.

Table 2. Mean (SD) naming latencies in ms for each condition

	No friends, no enemies	Many friends, no enemies	No friends, many enemies
UPPER	594.3 (77.2)	563.2 (53.5)	575.9 (55.8)
Lower	583.5 (102)	568.7 (92.3)	585.6 (106)
aLtErNaTiNg	642.5 (119)	614.5 (121)	625.4 (118)

Mean reaction times were calculated by subjects and by items and analysed separately. Two-way analyses of variance were used to examine the effects of word type and case. In the subjects analysis, there was an effect of word type ($F(2, 138) = 54.1$, $p < .001$) but no reliable effect of case ($F(2, 69) = 2.1$, $p = .13$) and no significant interaction between the two factors ($F(4, 138) = 1.7$, $p > .10$). In the items analysis, there was an effect of word type ($F(2, 160) = 11.8$, $p < .001$), an effect of case ($F(2, 160) = 53.5$, $p < .001$), and again no significant interaction ($F(4, 160)$, $p < 1.0$.

The absence of a reliable main effect of presentation type in the subjects analysis when subjects were treated as a random factor is taken to reflect the high inter-subject variation relative to the magnitude of the case of presentation influence. This was confirmed by a further analysis in which subjects within groups were treated as a fixed factor. This analysis found a clear effect of presentation type: by subjects ($F(2, 138) = 113.9$, $p < .001$). The interaction was non-significant as in the analysis treating subjects as a random factor.

Word type differences were further examined by carrying out Bonferroni *post hoc* comparisons of the mean RT values for the three spelling-to-sound conditions. The tests examined friend (no friends, no enemies versus many friends, no enemies) and enemy (no friends, no enemies versus no friends, many enemies) effects separately. These analyses were again performed separately on data scored by subjects and by items. The enemy comparisons yielded a significant difference in the subjects but not the items analysis. In contrast, a significant ($p < .05$; this significance value will be used hereafter) spelling-to-sound friends effect was obtained both by subjects and by items.

In combination with the data shown above, these results (particularly the absence of an interaction) confirm the effect of number of friends and also found no effect of spelling-to-sound enemies that was reliable in both by-subjects and by-items analyses.

Discussion

It had been observed (Brown, 1987*a*) that numbers of friends and enemies are confounded with orthographic neighbourhood size. It was therefore possible that the putative effect of spelling-to-sound friends was really due to orthographic neighbourhood size. Furthermore, a possible explanation for the absence of an enemies effect in Brown's word-naming experiment was that underlying influences of enemies and orthographic neighbourhood size had cancelled each other out. The present study addressed these issues by attempting to dissociate the purely orthographic influence of neighbourhood size from the phonological effects of spelling-to-sound characteristics. It was assumed on the basis of Parkin & Underwood's (1983) findings that the use of upper and alternating case would suppress the facilitative effects of orthographic unit familiarity on naming time but that it would allow any measurable effect of spelling-to-sound characteristics to remain. It was predicted that if an underlying effect of enemies existed, it would be seen more clearly in the upper and alternating relative to the lower-case conditions of the experiment. It was also predicted that if the putative effect of friends was a genuinely phonological effect it should remain under all case presentations.

The results of Expt 1 clearly indicate that the stimulus presentation case manipulation did not interact with spelling-to-sound effects on word-naming time. As in Brown (1987*a*), there was no main effect of enemies in the by-items analysis. There was a small effect of spelling-to-sound enemies in the by-subjects analysis, probably due to a minority of non-representative items. The absence of an interaction may be taken as evidence that an underlying enemies effect was not being cancelled by the confounded effect of orthographic structure. Although the effect of friends appeared to be robust across conditions, and therefore genuinely phonological in nature, the absence of a reliable effect of enemies may reflect the relatively low frequency of the relevant enemies (Jared *et al.*, 1990). We return to this issue later.

We should note that the results of this study do not inform us whether it is the *number* of spelling-to-sound friends that facilitates naming time, or the *combined frequency* of friends. The most relevant existing data come from the study of Jared *et al.* (1990), which presents evidence that, for the enemies effect that they obtained, it was the summed frequency of enemies rather than the number of enemies *per se* that was the relevant factor. We cannot yet say whether the same will be true for the spelling-to-sound friends effect that we have obtained.

EXPERIMENT 2

The results of Expt 1 suggest that the presence of spelling-to-sound friends is a characteristic that has an important independent effect on word-naming time with the materials we have used.

However, there is another factor not considered in previous studies which might prima facie be expected to influence word-naming time. This is the number of *rhymes* that a word has, i.e. its number of purely phonological neighbours. Independent of the purely orthographic characteristics of a given word, and independent of its spelling-to-sound attributes, we might expect that certain commonly pronounced phonological subsequences might be named more quickly simply because of the relative ease with which more commonly used articulatory programmes can be prepared. For example, we classified the friendless word SOAP as 'unique' because it is the only four-letter word in English ending in -OAP, and *a fortiori* it is the only four-letter word in English containing the spelling-sound correspondence -OAP -> /wp/. However, SOAP does have many phonological neighbours (rhymes), e.g. HOPE, ROPE, etc. And it is at least conceivable that the high frequency of this sound sequence might render SOAP easier to pronounce than a word with similar orthographic and spelling-sound characteristics but fewer or no phonological neighbours. The word CUSP, along with a few idiosyncratic items such as KILN and FILM, is almost the only four-letter word in English with no phonological or orthographic friends.

Furthermore, if the number of phonological neighbours that a word has is influential in determining word-naming latency, then the existence or at least the magnitude of the putative spelling-to-sound effects could be compromised for the following reason. Although reliable effects of spelling-to-sound enemies were not found in Expt 1 such effects as have been reported elsewhere are likely to be confounded with our rhyming factor. Consider, for example, an exception word such as PINT. This is likely to be a low-rhyme word as it may contain an infrequently occurring phonological subsequence. But a consistent word like HILL is consistent by virtue of its having phonological neighbours (which also have the same orthography). So HILL must have many rhymes (PILL, TILL, FILL, MILL, etc.). The number of rhymes that a word has will not be perfectly correlated with its spelling-to-sound characteristics, because words may have rhymes with different orthographies (as in the SOAP example above) and whether or not such different orthography rhymes exist makes no difference to a word's spelling-to-sound characteristics. But in general, we might expect consistent words to have more rhymes than words with exceptional pronunciations, because a consistent word must always have some rhyming neighbours while an exception word need not. Thus, any evidence for an influence on processing of number of rhymes could compromise the putative spelling-to-sound effects discussed hitherto. For this reason, Expt 2 looks for an effect of a word's number of rhymes on that word's naming latency, with orthographic and spelling-to-sound characteristics held constant.

It is worth relating this argument to the recent debate concerning the locus of word-frequency effects in naming. McCann & Besner (1987) have discussed the possibility that word frequency effects in the word-naming task reflect the post-lexical access process of assembling an articulatory speech response. It has been assumed that if lexical frequency effects in word naming have an 'output' locus, i.e. reflect the processes of articulatory motor programme assembly, for example, rather than any frequency-sensitive lexical access stage, then effects of lexical frequency should remain even in delayed naming tasks. This is because in delayed naming, i.e. when the word is not pronounced until a signal occurs some interval after the word itself has been presented, it is assumed that lexical access is completed and so any residual frequency effects cannot reflect the lexical access process. Balota & Chumbley (1985) did find residual effects of word frequency in a delayed naming task, and concluded that the word frequency effect in the naming task reflects production processes as well as access mechanisms. Forster & Chambers (1973), in contrast, found that a delay did abolish the word frequency effect. McRae, Jared & Seidenberg (1990) found that a sufficiently long delay did abolish word frequency effects when the delay was calibrated for individual subject-naming speed. As McRae *et al.* (1990) point out, there may in any case be no discrete lexical access stage in recent models of word naming (e.g. Seidenberg & McClelland, 1989). The delayed naming studies just described seem to argue against an explanation of word frequency effects purely in terms of articulatory–motor programming. However, they are not conclusive evidence against the possibility we outlined above, namely that the frequency of phonological subunits (or fragments of articulatory–motor programmes) may independently influence word-naming latency. In a non-delayed naming task it is hard to determine how much motor programming/priming could take place in advance of the signal in a delayed naming task.

In view of the potential importance of this possibility for the interpretation of the putative spelling-to-sound effects, Expt 2 was designed to look for the effects of the rhymes variable on word-naming latency.

Method

Subjects

Twenty-six undergraduate students from the University College of North Wales, Bangor participated in individual experimental sessions. Subject age ranged from 19 to 23 years. All were native English speakers and had normal or corrected-to-normal vision and normal reading skills. They were not paid for their participation.

Materials

The stimulus materials comprised 13 word pairs that were matched as closely as possible (within each pair) on spelling-to-sound friends and enemies, word frequency, initial phoneme and number of letters, but which varied in their number of rhymes (phonological neighbours). These are listed in the Appendix. One of each pair had many rhymes (high rhyme stimuli) and one had relatively few rhymes (low rhyme stimuli). All words had regular spelling-to-sound correspondences. The spelling-to-sound friends factor was controlled for by selecting word pairs that were similar in terms of having the same number of rhymes spelt in the same way as themselves, but which varied in their number of rhymes spelt differently. For example, the high rhyming word DALE has a total of 40 rhymes, 13 of which have the -ALE spelling. DALE was matched with DAME, which has only 17 rhymes but nevertheless has 11 phonological neighbours with the same -AME spelling. Thus, each high-rhyme word had approximately the same number of similarly spelt rhymes as its low-rhyme counterpart and differed from the low-rhyming word only in terms of the numbers of differently spelt phonological neighbours.

Construction of the stimulus materials was tightly constrained by the need to control for such a wide range of spelling-to-sound and lexical variables, and any attempt to match the word pairs on additional attributes such as their purely orthographic characteristics would have rendered the task impossible. However, there was some concern that the high- and low-rhyme words might have varied in their orthographic regularity and that such a confound might cause an effect in this experiment. In order to evaluate this possibility, positional bigram frequency values were calculated for the two-word sets. The high-rhyme words had a higher mean bigram frequency than the low-rhyme words (5190 vs. 3700). However, a comparison of these data in a pairwise t test showed that the difference was non-significant ($t(12) = 1.59$, $p > .10$). Orthographic neighbourhood characteristics were assessed by calculating Coltheart's N measure for all the items. Mean N values were 7.9 for high-rhyme words and 6.4 for low-rhyme words, a non-significant difference ($t(12) = 1.13$, $p > .10$). It was therefore assumed that any response time effect obtained in Expt 2 could not be attributed to purely orthographic differences between the two word types.

Procedure

Subjects took part in short, individual word-naming sessions in which 20 practice trials preceded the 26 experimental naming trials. The naming task proceeded in exactly the same way as in Expt 1. There was no additional experimental manipulation except for a word order condition that was intended to counteract practice effects on the response time data. The first word order was determined at random. Half the subject group was exposed to the first order; the other half received a second order that was a simple reversal of the first.

Results

Response time data pairs were excluded from the analyses if either RT was associated with a reading error, hesitation, voice key failure or accidental activation. Data loss was minimal: 18 subjects provided a complete set of 26 latency values; three subjects had one pair excluded; four lost two pairs; and a further subject lost three pairs. The latencies were again averaged separately over subjects and items and outliers (more than 2.5 SD from the relevant mean) were replaced with overall subject or item means where necessary (less than one outlier per subject or item).

The grand means from the subject and item data are shown in Table 3. The subject data yielded an overall 7 ms disadvantage for the high-rhyme words; the items data produced a smaller difference (5 ms). Related t tests showed that the effect was clearly non-significant (by subjects: $t(12) = 1.52$, $p > .10$; by items: $t(12) = 0.87$, $p > .10$).

Table 3. Mean (SD) naming latencies in ms for each condition

	High rhyme	Low rhyme
By subjects	526.0 (101)	519.8 (94.7)
By items	522.2 (27.1)	517.4 (20.4)

Discussion

We found no effect of the number of rhymes a word has on the naming latency of that word. Although this interpretation relies on the absence of an effect in Expt 2, the between-subjects design was sensitive enough to have detected any effect of sufficient magnitude to compromise the spelling-to-sound effects discussed earlier. This appears prima facie to rule out models of phonological or articulatory assembly which involve the activation of common programme fragments or subsequences in a frequency-sensitive manner. We note that the materials we used varied on both number of rhymes and combined frequency of rhymes. It is unlikely that these factors had opposite effects that cancelled each other out, so the absence of any difference between the conditions suggests that neither factor is influential. Furthermore, we note that there were orthographic differences between the high-rhyme and low-rhyme sets of items, although these were not statistically significant. These orthographic differences, if they had any effect, would have favoured the high-rhyme items as would the phonological differences that the experiment was designed to examine. The absence of any naming time differences therefore suggests that the orthographic characteristics were not having any significant effect.

Finally, and most crucially for the present investigation, it seems unlikely that the spelling-to-sound effects that have been reported in the literature need to be reinterpreted as purely output effects.

EXPERIMENT 3

Experiments 1 and 2, in combination with previously published research, have excluded some alternative potential explanations of the friends effect and the absence of a spelling-to-sound enemies effect originally reported in Brown (1987*a*). Experiment 1 of the present paper is consistent with these earlier results in that it found effects of spelling-to-sound frequency (number of friends) but no reliable residual effects of number of enemies when friends were controlled and when experimental conditions that were predicted to increase the probability of obtaining a true enemies effect were imposed.

Recently, however, Seidenberg & McClelland (1989) have described an experiment in which they found an effect of a word having enemies even when its number of friends was held constant. They therefore concluded that there are in fact effects of both number of friends and number of enemies, and indeed, this is what is predicted by their connectionist model. Our Expts 1 and 2, and indeed the Brown (1987*a*) experiments, focused on the previously unreported friends effect while also failing to find any independent effect of number of enemies. Although the results that we have reported therefore argue unequivocally for a friends effect, we cannot confidently exclude the possibility of a small (12 ms in Seidenberg & McClelland, 1989) residual enemies effect which our experimental materials were not sensitive enough to detect. The constraints of constructing matched triplets of items for these experiments inevitably led to the use of a smaller number of items than were used in the Seidenberg & McClelland experiment.

A further possible explanation for the failures to find a reliable effect of number of enemies lies in the nature of the materials used both in Expt 1 of the present paper and in Brown (1987*a*). Jared *et al.* (1990) point out that the exception words used in the Brown (1987*a*) study (which were also used in Expt 1 reported above) had relatively low summed enemy frequencies—only four of the 21 items had summed enemy frequencies greater than 250 per million. Jared *et al.* found an effect of enemy frequency in their Expt 1, and it is probable therefore that this factor could explain our failure to find any effect of number of enemies.

In view of the importance of this putative enemy effect, and its apparent discrepancy with the results of our Expt 1, we first attempted to replicate their finding. In the second part of this study, we examined the extent to which additional factors in the original construction of the stimulus materials could have been responsible for the putative consistency effect reported by Seidenberg & McClelland (1989). This was achieved by examining the characteristics of the stimulus materials in terms of a wide range of word attribute variables.

Method

Subjects

Twenty-two undergraduate students from the University College of North Wales, Bangor participated in individual experimental sessions. Subject age ranged from 20 to 30 years. All were native English speakers and had normal or corrected-to-normal vision and normal reading skills. They were not paid for their participation.

Materials

The stimulus materials comprised 80 words in two equal sized sets, referred to as 'consistent' and 'inconsistent' words respectively. They were taken from the experiment described by Seidenberg & McClelland (1989) which obtained an effect of spelling-to-sound consistency that was independent of spelling-to-sound frequency. Consistency is defined in terms of the pronunciation of the stimulus word's orthographic neighbours. Consistent and inconsistent words all have regular pronunciations and so relatively frequent spelling-to-sound correspondences (i.e. many friends). However, whilst a consistent word's neighbours all have the same pronunciation pattern, an inconsistent word has at least one orthographic neighbour with an exceptional pronunciation. In other words, consistent words have only spelling-to-sound friends whilst inconsistent words have enemies as well as friends.

As reported by Seidenberg & McClelland (1989), the sets of consistent and inconsistent words were matched overall on mean word frequency, number of friends, the summed word frequency of the friends, word length, and the words' orthographic and phonological error scores derived from the Seidenberg & McClelland (1989) computational word-naming model. The two samples were assumed to vary only in their mean number of enemies, which is the defining characteristic of spelling-to-sound inconsistency.

Procedure

Subjects took part in individual word-naming sessions in which 13 practice trials preceded the 80 experimental naming trials. The practice stimuli all contained final vowel + consonant clusters that did not occur in any of the experimental stimuli. The naming task proceeded as in the preceding experiments. There were no additional experimental manipulations. Word presentation order was determined at random and then used throughout the experiment.

Stimulus word ratings

The aims of the additional analyses that are reported below required that we obtain subjective ratings of three attributes of the words used as stimuli in the word-naming experiment. The measures were word familiarity, age-of-acquisition and imageability. The instructions and method used to obtain these measures here were identical to the procedures used in similar, previously reported research (e.g. Gilhooly & Logie, 1980*a*, *b*).

A teaching group of 60 first-year undergraduate students at UCNW, Bangor volunteered to participate in a word rating session. Subjects were provided with an instruction and word rating booklet that required ratings of either word familiarity, age-of-acquisition or imageability to be made for each of the 80 word-naming stimuli. The three types of rating booklet were distributed amongst the group such that subjects were randomly assigned to one of the three word rating conditions.

The subjects first read detailed instructions about the attribute rating dimension they were to use, and had practice with a small sample of words. Ratings were made on a seven-point scale where the low end of the scale (l) represented either early age-of-acquisition, low familiarity or low imageability. Subjects were required to circle the rating value they considered to be most appropriate for each word. The 80 stimulus words were printed in a column on the left side of each of three rating sheets, with a seven-point scale to the right of each word. Subjects received different sheet orders at random.

Results of experiment

Reaction times from naming trials in which the words were correctly pronounced and not associated with any accidental premature activation or failure of the voice key were included in the calculation of subject and item RT means. Data from one subject were excluded from the analyses because the error rate was over 10 per cent. All other subjects had minimal data loss. Data from two items were also discarded. These were the inconsistent word LONE, which had been misspelt in the materials prepared for computer presentation, and a corresponding but randomly selected consistent word (HIKE). Although the items in the stimulus sample were not matched in pairs, equal numbers of RT values for consistent and inconsistent items were included in the calculation of each subject and item mean. Outlying RT values were calculated with reference to, and replaced by, overall subject and item means respectively.

The overall mean RT values are shown in Table 4 and indicate that consistent words were pronounced about 13 ms faster than inconsistent words (this compares with an effect size of 12 ms reported in Seidenberg & McClelland (1989)). The subject and item mean naming RTs were compared in separate t tests which indicated that there was a clear effect of consistency on word-naming time (by subjects: $t(20) = 3.5$, $p < .01$; by items: $t(76) = 2.3$, $p < .05$). Thus, the consistency effect reported by Seidenberg & McClelland (1989) was closely replicated in the present experiment.

Table 4. Mean (SD) naming latencies in ms for each condition

	Inconsistent	Consistent
By subjects	536.7 (70.5)	524.6 (64.6)
By items	539.2 (31.5)	525.8 (19.7)

Results of stimulus word attribute analysis

The next stage of our examination of the consistency effect was to consider other potentially relevant attributes of the Seidenberg & McClelland (1989) stimulus word sample and to test the possibility that consistent and inconsistent words varied

Table 5. Mean spelling-to-sound and lexical attribute values of the Seidenberg & McClelland (1989) stimuli

	Inconsistent	Consistent	t
Friends	10.0	10.6	.42
Enemies	3.4	0.0	6.6**
Rhymes spelt differently	11.7	11.5	.1
Total rhymes	21.7	22.1	.1
Frequency	6.4	5.5	.7
Length	4.5	4.5	.5
Bigram frequency	5590	5972	.5
Coltheart's N	6.3	6.4	.1
Familiarity	3.9	4.2	1.1
Age-of-acquisition	4.1	4.2	.4
Imageability	4.8	4.8	.2

**$p < .01$.

significantly on dimensions other than their number of spelling-to-sound enemies. It was assumed that if the two word types differed on other dimensions as well as on consistency, then such variation might underlie the reported consistency effect.

Several of the variables that Seidenberg & McClelland (1989) had used in matching their consistent and inconsistent word samples were also constructed and included in the present analysis. These were word length, word frequency, spelling-to-sound frequency (number of friends), and number of enemies. We did not construct, as they did, the orthographic and phonological error scores derived from their computational model.

Various additional measures reflecting further phonological characteristics as well as other attributes of the stimulus words were also either constructed from published sources or obtained from the word rating sessions as described above. These were the mean rated word familiarity, age-of-acquisition and imageability measures (obtained by averaging the raw rating data across each rating subject group), positional bigram frequency (from Solso & Juel, 1980), number of orthographic neighbours (Coltheart's N), total number of rhymes, and number of rhymes spelt differently. Note that the number of rhymes spelt differently measure was the dimension underlying the high- and low-rhyme conditions in our Expt 2, and that a number of similarly spelt rhymes measures had already been included, as it is equivalent to the number of friends.

We were interested in the potential effects of these additional attribute measures because it was possible that they would be confounded with the measures controlled for within the stimulus sample and could therefore be responsible for at least some part of the apparent consistency effect. Word familiarity, age-of-acquisition and imageability have all been shown to independently affect response latency in various lexical tasks including word naming (e.g. Brown & Watson, 1987; Gilhooly & Gilhooly, 1979; Gilhooly & Logie, 1982).

The mean values of these variables for consistent and inconsistent words are shown in Table 5. Whilst there was some small difference between the consistent and inconsistent means in most cases, the results of unrelated t tests performed for each measure indicated that the two samples varied significantly only on the number of enemies dimension.

Thus, the measures taken by Seidenberg & McClelland in their stimulus matching had not only removed any significant variability between consistent and inconsistent words on most of the dimensions that Seidenberg & McClelland had considered relevant, they had also eliminated variance in terms of the additional potentially confounded variables examined here. It seemed unlikely then that any other potential influences were responsible for the reported consistency effect.

Discussion

Experiment 3 has replicated the evidence reported in Seidenberg & McClelland (1989) for an effect of consistency. In conjunction with the subsidiary analyses that were carried out here, this demonstrates that there is a true influence of a word's spelling-to-sound inconsistency (i.e. whether or not it has enemies) even when number of friends is held constant. However, the size of this effect appears to be only about 13 ms, which is substantially smaller than it was previously assumed to be. We attribute the failure of Expt 1 of the present paper to obtain spelling-to-sound enemy effects that would generalize across items to the small magnitude of the effect in combination with the nature of our stimulus materials (the low summed frequency of the exception words' enemies, as suggested by Jared *et al.*, 1990). In our experiments, the constraints of devising matched triplets of words meant that each comparison involved only 21 pairs of items (cf. the 80 words used by Seidenberg & McClelland). We discuss apparent inconsistencies between existing results in the general discussion that follows.

General discussion

The main experimental findings of the present paper may be summarized as follows. Experiment 1 replicated the findings of Brown (1987*a*), indicating that there is an effect of a word's number of friends (orthographic neighbours pronounced the same) on naming latency for that word. This experiment, taken in combination with other results, strongly suggests that this is a genuine spelling-to-sound effect that is independent of orthographic factors.

Experiment 2 found that the overall number of rhymes a word has does not affect that word's naming latency, thus excluding one potential explanation of the spelling-to-sound friends effect obtained in Expt 1. Experiment 3 replicated the Seidenberg & McClelland (1989) finding of a small residual effect of spelling-to-sound inconsistency (enemies) even when all other factors are accounted for. Taken as a whole, the results suggest that both friends and enemies combine to determine word-naming latency, while phonological unit output frequency does not.

Jared *et al.* (1990) have recently reported research which comes to a similar conclusion. They report three experiments which find effects of spelling-to-sound enemies on word-naming latency, and a fourth experiment which shows that such effects do not appear in a lexical decision task where the non-word environment is constructed so as to encourage subjects to focus on orthographic rather than phonological information as the basis for making the lexical decisions (Waters & Seidenberg, 1985). This lexical decision task result can, therefore, be taken as further evidence that the effects discussed throughout this paper are phonological rather than orthographic in nature.

There is, however, an apparent inconsistency between the results of Jared *et al.* and our results, for in their Expt 2 they found an effect of friends that was significant by subjects but not by items in both error and RT analyses. This contrasts with the clearer effects of this measure we have obtained. As discussed above, the most likely explanation of this appears to be that our low-friend words were generally the *only* words in which the relevant spelling-to-sound correspondence occurred (i.e. they had no friends at all). In the Jared *et al.* comparison between low-friend words and high-friend words, however, even the low-friend words had several friends, albeit fewer than the number of friends for the contrasted items. As they suggest themselves, it therefore seems probable that number of friends will only have a reliable effect when the low-friend items have no or at least very few friends.

On the basis of our own results, along with those of Seidenberg & McClelland (1989) and Jared *et al.* (1990) we have concluded that word-naming latency is affected both by a word's number of friends and by its number of enemies. Furthermore, the overall pattern of findings is entirely predictable on the assumption that it is the *relative proportions* of friends and enemies that determines whether an effect of enemies will be experimentally detectable.

Some other recently reported evidence is relevant to this conclusion. Venezky & Massaro (1987) computed a number of different measures of orthographic and spelling-to-sound word characteristics, and found that their 'fluency' measure of spelling-to-sound attributes independently correlated with naming latency for low frequency words when the correlations of other variables were partialled out. The 'fluency' measure that they computed was based on the number of times a particular spelling-to-sound correspondence occurred relative to the sum of all correspondences for the relevant graphemic unit. Their measure was based on many different graphemic units in the words, but if one takes the 'rime' of a word (its vowel and following consonants) to be the relevant processing unit (Treiman & Chafetz, 1987), our measure of spelling-to-sound frequency (number of friends) is clearly related. We therefore take the Venezky & Massaro results as tentative support for our claims.

Kay & Bishop (1987) report a *post hoc* analysis of some of their own data in which they found that, 'Consistent words with few neighbours took no longer to pronounce than consistent words with many neighbours (whether they were of high or low individual frequency), even though they had a substantially lower *combined* lexical frequency'. This analysis is consistent with the account outlined above, namely that effects of 'number of friends' will only emerge when the low-friend words have no friends at all. Taraban & McClelland (1987) also report *post hoc* analyses that find a residual effect of number of enemies even when number of friends is held constant. This is consistent with our general conclusion that both friends and enemies are influential in determining pronunciation latency.

We now briefly summarize the implications of these results for models of word naming. Brown (1987*a*) presented a computational model of word naming in which only friends and not enemies determined word-naming latency. Seidenberg & McClelland (1989) describe a much larger connectionist model of word naming, and show that it predicts effects of both friends and enemies. They also show that the model provides an excellent fit to the data reported by Brown (1987*a*), and the data reported here are also entirely consistent with their model. In general, the combination of friend and enemy effects arises naturally as a consequence of the way connectionist models learn, for the strength of each association between orthographic and phonological units will, however the intervening hidden units dispose themselves, ultimately be a function of the predictiveness of that correspondence. As Jared *et al.* (1990) describe the operation of the Seidenberg & McClelland (1989) model: 'The effects of each training trial are superimposed on the weights: the alternative pronunciations of a letter string push the weights in competing directions during the training phase instead of directly competing with each other during processing as in Glushko's (1979) model'.

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Appendix

Materials used in Expt 2

SITE	SAVE
SNACK	SCRUB
DALE	DAME
STEER	SCOUT
TILE	TORN
SPITE	SNAKE
PEEL	PUNK
POLE	PLUG
SLATE	SLUMP
MEEK	MAZE
FLEET	FLUSH
SPEED	SLEEP
CANE	CLAD