Neurolinguistic Analysis of Spelling Errors in Thai

Jack Gandour
Purdue University
West Lafayette, IN 47907 USA

Recent efforts at understanding the cognitive and linguistic mechanisms that underlie spelling have focused increasingly on the role played by specific processing components implicated in the areas of reading, writing, and repetition (Caramazza & Miceli, 1989, 1990). This approach has led to the formulation of detailed characterizations of the functional architecture of the spelling process. A schematic representation of the architecture for the writing system indicating the functional components and their interconnections is shown in Figure 1.

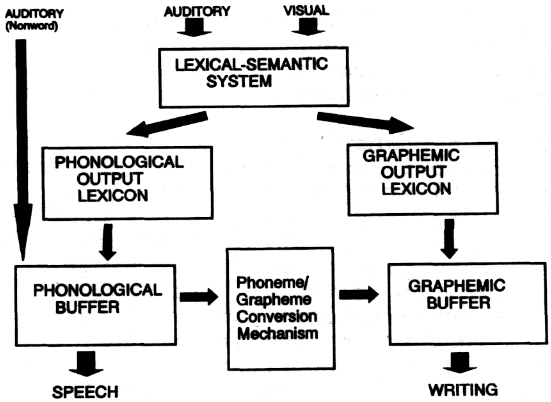

Figure 1. Schematic representation of the functional architecture for spelling.

The various tasks represented in this diagram include repetition and spelling to dictation, oral reading, and oral/written picture naming. The 'lexical-semantic system' is a long-term store that contains the meanings of words. The 'phonological output' and 'graphemic output' lexicons are both long-term stores. The former associates lexical-semantic representations with output phonological representations corresponding to morphemes or words, the latter with graphemic representations. The 'phonological buffer' is a working memory component that temporarily stores phonological representations. The representations held in the buffer are specified in an abstract phonological code. The 'phoneme-grapheme conversion mechanism' is a computational component that converts phonemes or syllables into orthographically-permissible graphemic representations. The 'graphemic buffer' is a short-term store that temporarily holds graphemic representations for conversion into specific letter shapes (written spelling), letter names (oral spelling), or letter keys (typing).

Caramazza and Miceli (1989, 1990) have provided strong evidence to support not only the functional architecture, but also specific proposals about the structure of orthographic representations. They proposed that graphemic representations are multidimensional structures similar in principle, but not in content, to multi-tiered phonological representations in autosegmental phonology (Goldsmith, 1989). Analogous to consonants, vowels, and syllables in the phonological domain are graphoconsonants, graphovowels, and graphosyllables in the orthographic domain.

As far as alphabetic writing systems are concerned, previous research on spelling errors has been directed primarily to English, French, and Italian. Although accent markers are provided to represent suprasegmental units of stress in both French and Italian, they play a relatively minor role in their writing systems. In contrast, Thai provides symbols to represent the suprasegmental units of tone, which play a major role in the Thai writing system. Such a writing system affords us the opportunity to evaluate the extent to which tonal errors are quantitatively and qualitatively similar to consonant and vowel errors.

In this paper, we report a detailed analysis and interpretation of this patient's spelling errors within the aforementioned architectural model of the writing system.

Method

Subject

The patient was a 55-year-old, nonfamilial left-handed, monolingual speaker of Thai who had suffered a stroke. Neuroradiological findings indicated an infarct in the left temporoparietal region. At the time of this study, 9 years postonset, he was diagnosed with conduction aphasia, and his writing disorder was symptomatic of a dominant parietal-temporal agraphia.

Thai Writing System

Thai is a tone language, and tones are consistently marked in the orthography (Danvivathana, 1987). There are 44 consonant letters in the Thai script representing 11 stops, 3 spirants, and 7 sonorants. Thai consonant letters are divided into three tone classes: middle, high, and low. There are 23 vowel symbols in the Thai script representing 18 monophthongs, 9 short and 9 long vowel phonemes, and 3 diphthongs. Simple vowel graphemes are composed of one symbol; complex vowel graphemes of two or three symbols.

There are four tonal markers in the Thai writing system representing five lexical tones: mid, low, falling, high, rising. The mid tone is unmarked. All tonal markers are superscripts. The phonetic interpretation of a tonal marker depends on the tonal class of the syllable-initial consonant letter and the type of syllable with which it is used.

Materials

A set of 454 picturable test items was chosen consisting of familiar objects, colors, forms, actions, and numbers. In terms of grammatical category, 75% of the items were nouns, 5% verbs, 4% numbers, and 16% noun classifiers that had been used in a previous study in which this patient also participated (Gandour, Buckingham, & Dardarananda, 1985). In terms of word length, 67% of the items were monosyllabic, 26% bisyllabic, and 7% trisyllabic or greater.

Procedure

A written confrontation naming task was used to assess the patient's ability to spell single words. Pictures of each of the test items were presented once only to the patient. He was instructed to write down his responses as quickly as possible though there was no time limit for the task. He was never cued or corrected in his responses.

Analysis

The method for investigating serial position effects was taken from Wing and Baddeley (1980). Letters or symbols in words of differing lengths were all assigned to one of five standardized serial positions according to the procedure shown in Table 1.

Each written element (consonant letter, vowel symbol, tonal marker, letter silencer) in a word was assigned to a separate position. In cases where the vowel symbol occurs above or below the consonant letter and/or where the tone symbol occurs above the consonant letter, the left-to-right order of progression is from the consonant letter to vowel symbol to tone symbol. This order of progression is the order in which these symbols are actually produced in normal Thai writing. For purposes of distributional analysis, all errors in a word were counted.

Table 1
Normalization of Word Length

	Position				
Total No. of Symbols	1	2	3	4	5
1	-	-	1	-	-
2	1	-	-	-	2
3	1	-	2	-	3
4	1	2	-	3	4
5	1	2	3	4	5
6	1	2	3,4	5	6
7	1,2	3	4	5	6,7
8	1,2	3	4,5	6	7,8
9	1,2	3,4	5	6,7	8,9
10	1,2	3,4	5,6	7,8	9,10
11	1,2	3,4	5,6,7	8,9	10,11
etc.					

Spelling errors were classified into four mutually exclusive categories: substitutions, additions, deletions, and reversals. Following the scoring procedure in Caramazza and Miceli (1990), 1 point was given to the position where the error occurred for substitutions and deletions. For addition errors in the middle of a word, 1/2 point each was given to the position before and after the inserted letter; at the beginning or end of a word, 1 point was assigned to positions 1 or 5, respectively. For reversal errors, 1 point was assigned to both positions corresponding to the exchanged letters or symbols. In the case of syllable reversals, the positions were taken to be the initial symbols of the exhanged syllables.

To determine whether the spelling errors were primarily motivated by the sounds or shapes of the letters, it was necessary to provide a quantitative measure of phonological and visual similarity between the target letter/symbol and error. The Halle and Clements' (1983) set of phonological features was used to classify the Thai consonant sounds, and Gandour and Potisuk's (1990) set of visual features to classify the Thai consonant letters.

Results

Spelling Accuracy

Of the total set of real words ($\underline{N}$ = 454), 46% were spelled correctly on the first attempt. Performance varied as a function of word length: 1-syllable, 67% correct; 2-syllable, 38%; 3^{+}-syllable, 33%. The mean length of correctly spelled words (4.2 symbols) was significantly shorter than that (5.4 symbols) of incorrectly spelled words, $\underline{t}(452) = 5.52$, $\underline{p} < .0001$.

Of the words in error, 34% elicited more than a single attempt. These multiple attempts at a target word ended in the correct spelling 92% of the time. The mean length of such sequences was 3.6 attempts, ranging from 2 to 8. Over half (54%) of total attempts in error contained one error only. Including items spelled correctly on second or later attempts as well as initial attempts, 63% were spelled correctly. Of the classifier subset, 65% were spelled correctly in comparison to 76% in oral confrontation naming (Gandour et al., 1985, p.550) [$X^2(1, \underline{N} = 180) = 2.17$, n.s.].

Position of Errors in a Word

The distribution of errors as a function of relative position in the word is shown in Figure 2. Errors did not occur with equal probability over all letters and symbols within a word [$X^2(4, \underline{N} = 504) = 102.07$, $\underline{p} < .0001$]. Errors were most likely to occur in the final position (37%). Errors that occurred in the final three positions accounted for 70% of total errors.

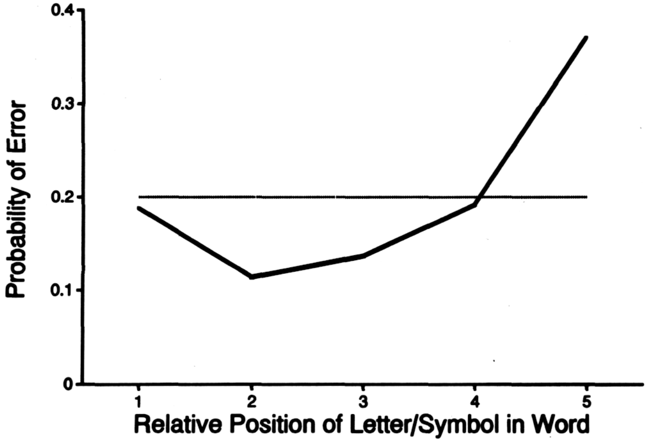

Figure 2. Probability of error as a function of the relative position of the erroneous symbol(s) in the word. An estimate of expected frequencies under the null hypothesis is .20 at each position as shown by the dotted line.

<u>Distribution of Errors across Graphemic Units</u>

The error rates associated with graphemic consonants, vowels, and tones were not significantly different [$X^2(2, \underline{N} = 430) = 4.25$, n.s.]. The distribution of error types, however, varied as a function of the graphemic unit (Figure 3). Consonants and vowels were highly similar [$X^2(3, \underline{N} = 337) = 2.80$, n.s.]. In contrast, the distribution for tones was dissimilar from that of consonants and vowels [$X^2(3, \underline{N} = 430) = 118.99$, $\underline{p} < .0001$]. Substitutions predominated in both consonant and vowel errors; deletions accounted for the majority of tone errors.

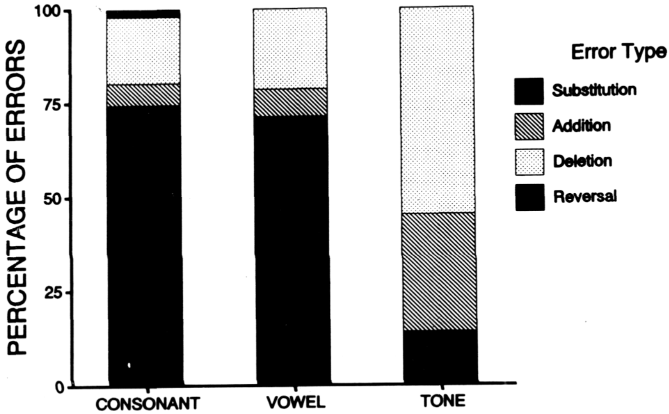

Figure 3. Types of spelling errors in a word as a function of the graphemic unit.

Distribution of Errors across Vowel Symbols

There was no significant difference between the observed and expected distributions of errors for simple and complex vowel graphemes [$X^2(1, \underline{N}=408) = 1.72$, n.s.], indicating that the number of strokes corresponding to a vowel grapheme had no influence in determining whether or not a vowel error occurred.

Phonological versus Visual Features of Errors

An analysis of the patient's consonant letter substitution errors ($\underline{N}$ = 181) in terms of phonological and visual similarity revealed that his errors were primarily phonological in nature. The average phonological distance between the target letter and substituted letter was 2.74 features, whereas the average visual distance was 3.62 features. The results of a Wilcoxon matched pairs signed-rank test yielded a significant difference between distributions of phonological and visual distances ($\underline{z}$ = 4.56, df = 180, $\underline{p} < .0001$).

Types of Errors

Examples of errors involving consonants, vowels, and tones are shown in Figure 4. Consonant errors resulted from substitutions (4a-b), additions (4c), deletions (4d), and reversals (4e); vowel errors from substitutions (4f-g), additions (4h), and deletions (4i); tone errors from substitutions (4j-k), additions (4l), and deletions (4m). In (4a) and (4b), the target consonant letter and the error exhibit phonetic similarity in terms of manner and place of articulation, respectively. No visual similarity is evident. The example in (4c), on the other hand, illustrates an error without phonetic motivation. There are a few syllable-initial consonant letter sequences in Thai which are pronounced as single consonants (Danvivathana, 1987, p. 143). In the case of <ทร>, pronounced as /s/, the sound pronounced differs from that of either of the two written symbols (/th/, /r/). Since <ทร> is a permissible letter sequence, the anticipation of <ร> most likely occurred during the conversion of phonemes to corresponding sequences of graphemes. Of the examples (4a-e), it is noted that four out of the five errors resulted in phonologically/orthographically permissible but non-occurring lexical items. Some errors, however, did result in semantically-unrelated words (e.g., 4f-g). The substitution error in (4f) also reveals both phonetic and visual similarity between the target and the substituted letter. Whereas in (4f) the target and the intrusion both occur in the same symbol position, this is not true in (4g). The target vowel < ั > appears above the intial consonant letter, the intrusion <า> after. The syllable-initial consonant letter sequence <ฉน> in (4h) is pronounced with an intruded vowel (/a/), even though the vowel itself is unwritten. The target word and the actual production in (4h) are homophonic. The choice of whether to write <ะ> in such consonant sequences is governed by a complex set of spelling rules (Danvivathana, 1987, pp.170-172).

Example (4i) shows one of the rare instances where the actual production violated phonotactic and graphotactic patterns. Examples (4j-k) illustrate that tonal substitution errors were also sensitive to phonetic similarity. In (4j), the falling tone is replaced by the low tone; in (4k), the high tone by the falling tone. No reversal errors were observed for either vowel symbols or tonal markers.

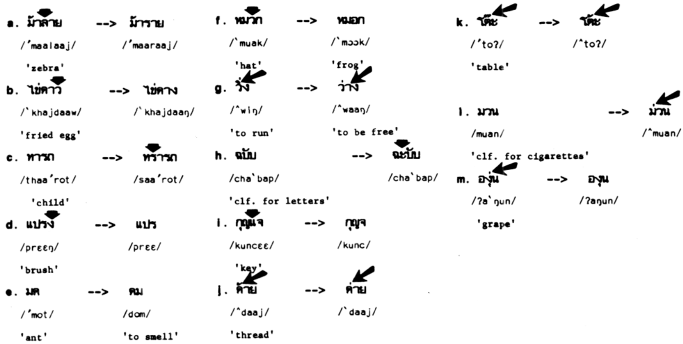

Figure 4. Examples of spelling errors involving consonants (a-e), vowels (f-i), and tones (j-m) from a written confrontation naming test.

Among consonant letter errors, 13% resulted in a concomitant tone error. Of the tone errors, 83% resulted from changes in the tonal markers themselves, 17% were secondary to either changes in syllable shape or changes in the tonal class of the syllable-initial consonant.

Discussion

Locus of Functional Deficit

The findings from the present study suggest that this Thai-speaking conduction aphasic suffered from an impairment of more than one component in the proposed architectural model of spelling. Although his pattern of impairment cannot be localized to any single cognitive component, the qualitative nature of his errors suggest that his spelling deficit is secondary to a phonological disturbance. It is assumed that retrieval of words from the graphemic output lexicon is not all or nothing. This patient encountered problems in gaining access to whole-word spelling representations in the graphemic output lexicon. Under such circumstances, he apparently used the alternate route in attempting to provide a spelling for the word. Here, too, he encountered difficulty because of his inability to generate and maintain a string in the phonological buffer.

This patient's spelling errors are clearly not to be ascribed to programming or execution of graphomotor patterns. He had no difficulty in direct copying of words and sentences (Gandour et al., 1982). His performance on auditory and reading comprehension subtests of a Thai aphasia exam (Gandour et al., 1982) indicate reasonably intact systems for both visual and auditory input of language. The similarity in error patterns across reading, repetition, and writing tasks reinforces the notion that pre-lexical processes are not responsible for this patient's writing deficit. His performance on oral and written naming of classifiers further indicates that his deficit was not restricted to the writing system. The relatively low frequency of semantic errors as well as his reasonably good performance (86%) in oral confrontation naming (Gandour et al., 1982), suggests that his principal deficit does not lie in the lexical-semantic system.

Both the phonological output and graphemic output lexicons are long-term storage components. The word-length and error position effects in his spelling performance, however, implicate a short-term buffer.

Almost all of his spelling errors resulted in phonologically-plausible nonwords regardless of whether the target spelling was regular or irregular. None of the complex vowel graphemes corresponding to single vowel phonemes were ever broken up in misspelled words. A number of errors involved conversions at the syllable level. His actual responses also reflected a sensitivity to the complex interaction between syllable structure and tone. Such findings indicate that the phoneme-grapheme conversion mechanism is reasonably intact.

The pattern of errors for words with multi-symbol graphemic units corresponding to single phonemes is relevant to the issue of phonotactic versus graphotactic constraints on his spelling performance. If the processing units are phonological, then complex vowel graphemes in Thai should behave as indissoluble units. Interestingly, none of the patient's errors violated the presumed unity of the graphemic units (cf. Caramazza & Miceli, 1990). If the graphemic buffer were implicated, one would expect that errors would correlate with graphotactic complexity. However, errors were no more likely to occur in words with complex vowel symbols than with simple vowel symbols.

With featural decomposition, errors would be predicted to reflect sensitivity to the degree of similarity between the target and intrusion. A high degree of phonological similarity between the target and intrusion grapheme is not predicted with damage to the graphemic buffer. On the other hand, a high degree of visual similarity is. The patient's consonant substitutions reflected a significantly higher degree of phonological than visual similarity. Thus, it is unlikely that the graphemic buffer is primarily responsible for his spelling deficit.

Substitution and addition errors involving consonants sometimes occur when an identical consonant is found in another syllable of the target word. It has been reported that such substitutions in speech errors involve segments sharing the same syllabic position (Buckingham, 1990). Though there were relatively few polysyllabic words in our spelling corpus, all consonant substitutions and additions obeyed this phonotactic constraint. A similar pattern of consonant substitution errors in polysyllabic words was observed in the patient's spoken output (Gandour et al., 1982). These similarities in patterns of errors in speaking and writing suggest that the locus of impairment must reside in a component that subserves both output modalities.

One of the principles that govern phonological syllable structure is the principle of sonority. This principle states that syllable onsets and codas are internally structured in terms of a sonority hierarchy with the most sonorous segments being closest to the vowel, the least sonorous segments being farthest from the vowel (Vennemann, 1972). According to Caramazza & Miceli (1990), if spelling errors are graphological rather than phonological in nature, then the principle of sonority ought not to influence spelling performance. Only one of the patient's errors violated phonotactic constraints of Thai. Similarly, none of his phonemic paraphasias violated the sonority principle (Gandour et al., 1982). Since graphotactic constraints are defined in terms of orthographic parameters, it is difficult to reconcile these findings with a primary functional lesion to the graphemic buffer.

The remaining component to be considered in our architectural model is the phonological buffer. Damage to the phonological buffer should affect performance in reading and repetition as well as writing. Indeed, the error patterns observed on oral reading and repetition tasks for this patient (Gandour et al., 1982) are similar to those on written confrontation naming. If the pattern of errors across the three tasks is the same, then it seems reasonable to assume that the co-occurrence of symptoms results from damage to the phonological buffer. Moreover, the majority of errors across all three tasks are subject to phonological constraints. As aforementioned, errors obeyed the sonority principle; complex vowel graphemes behaved as indissoluble single vowel phonemes; substitutions and additions across syllables obeyed syllable position constraints; featural decomposition of consonants revealed that substitutions were more likely to involve consonants that were highly similar in terms of phonological features; errors rarely violated Thai phonotactic constraints. Since it has a temporary storage function, damage to the phonological buffer should result in a stimulus length effect on performance. Predictably, this patient encountered more difficulty with longer stimuli in reading and repetition (Gandour et al., 1982) as well as in writing. If the phonological buffer stores a spatially-coded sequence of phonological units, damage should result in disruption of specific phonological units in the form of substitutions, additions, deletions, and reversals, all of which occur in his handwritten spelling errors. The fact that differences in distribution of error types varied depending on whether the phonological unit was segmental or suprasegmental is consistent with a hypothesized deficit to the phonological buffer. Moreover, all errors that involved a complex interaction of word-initial consonant, syllable structure, and tone did not violate Thai phonotactic constraints.

Another aspect of the patient's spelling performance that points to a deficit in the phonological buffer is the pattern of the ordinal position of errors. His distribution of errors in a word may be characterized as a rising pattern, indicating that errors occurred primarily in the final positions of words. The rising pattern has been interpreted to suggest that retrieval processes operate in a serial fashion from left to right (Wing & Baddeley, 1980). Due to mechanical constraints of handwriting, letters (sounds) occurring later in a word will be in the short-term buffer longer than those occurring earlier. With temporal decay of the buffer contents, letters (sounds) occurring later in the word will be more difficult to retrieve, increasing the probability of errors near or at the end of words (Wing & Baddeley, 1980).

Structure of Phonological and Orthographic Representations

In addition to the grapheme tier, CV tier, graphosyllable tier (Caramazza & Miceli, 1989, 1990), Thai tonal markers are written as superscripts, and clearly motivate a separate tonal tier in graphemic representations analogous to the tonal tier in phonological representations (Goldsmith, 1989). As argued above, however, this patient's tonal errors, as well as consonant and vowel errors, seem to have occurred in the phonological buffer instead of the graphemic buffer. The fact that the majority of tonal errors occurred independent of any disruption to consonants or vowels confirms a separate tonal tier in phonological representations. The fact that error rates for tones were the same as for consonants and vowels suggests that the tonal tier is equally vulnerable to disruption as the CV tier. The fact that the distribution of error types for tones differed from that for consonants and vowels is also congruent with the notion of a separate tonal tier.

Acknowledgments

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