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A functional deficit in the sensorimotor interface component as revealed by oral reading in Thai conduction aphasia

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ABSTRACT

The contemporary view is that a disruption in phonological encoding underlies the speech production deficit in conduction aphasia. We therefore expect to observe a commonality in phonological errors regardless of task – speaking, reading, or writing. A case report is presented of an oral reading task performed by a Thai conduction aphasic with evidence of localized damage in the left temporoparietal zone. He was instructed to read aloud selections from elementary school materials printed in Thai script at his own pace. A phonological analysis of substitution errors revealed that syllable-initial consonants were more vulnerable to disruption than vowels or tones. Tonal errors were seen to be a secondary consequence of a substitution error involving the syllable-initial consonant. His impaired performance is interpreted as evidence in support of a sensorimotor interface system that converts phonological representations derived from visual orthographic input into articulatory motor representations for speech output.

1. Introduction

1.1. Conduction aphasia

Conduction aphasia has attracted considerable scientific attention dating back to the late 1800s (Kohn, 1992). Historically, conduction aphasia was viewed primarily as a disconnection syndrome

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involving the white matter pathway between major language areas in the temporal and frontal lobes (Bernal & Ardila, 2009). The hallmark clinical sign of conduction aphasia was classically considered to be a repetition disorder. In the late 20th century, patients' difficulties associated with other speech production tasks besides repetition led to the recognition of two subtypes of the syndrome conduction aphasia, namely, *repetition* and *reproduction* (Shallice & Warrington, 1977). Lesions associated with the reproduction subtype of conduction aphasia have been frequently observed in left posterior temporoparietal regions (Damasio & Damasio, 1980; Dronkers, Pinker, & Damasio, 2000). Other sources of evidence also converge on the notion that cortical dysfunction alone is sufficient to produce the syndrome of conduction aphasia, including functional neuroimaging (Hickok, Buchsbaum, Humphries, & Muftuler, 2003), diffusion tensor imaging tractography (Glasser & Rilling, 2008) and aggregate analysis of fMRI and lesion overlap maps (Buchsbaum et al., 2011). Linguistically, the dominant contemporary view is that disruptions in phonological encoding are the source of the production deficit in conduction aphasia (Buckingham, 1992; Hickok, 2000; Kohn, 1984).

In their influential, dual-stream model of the functional anatomy of language (Hickok, 2009; Hickok & Poeppel, 2004, 2007), conduction aphasia results from cortical dysfunction in an area located in close proximity to the left posterior temporoparietal region involving dorsal aspects of the temporal lobe and parietal operculum. The dorsal stream itself is strongly left dominant. It is a multisensory region not limited to auditory input. As a sensorimotor interface of the dorsal stream (Hickok & Poeppel, 2007, Fig. 1, p. 395), it translates sensory-based representations (auditory or visual) into motor-based representations related to speaking, reading, and writing. In the auditory-motor interface system, conduction aphasia is believed to represent a disruption of vocal tract-related motor representations of complex sound sequences in speech (Hickok, Okada, & Serences, 2009) and music (Pa & Hickok, 2008). On an *oral* picture naming task, we previously reported that tones were better preserved than consonants or vowels in a Thai patient with conduction aphasia (Gandour, Akamanon, Dechongkit, Khunadorn, & Boonklam, 1994). In this paper, we bring evidence to bear on the nature of the sensorimotor interface system by evaluating phonemic errors made by this same patient on an *oral* reading task. On this task, the patient is required to convert an orthographic code to an articulatory-motor representation in order to read out loud.

1.2. Thai language and orthography

Thai is a major tone language of Southeast Asia. It exploits variations in pitch at the syllable level to signal lexical contrasts. In addition to phonological contrasts among consonants ($n = 21$) and vowels ($n = 21$), Thai has five phonemic tones: e.g., *khaa*^{mid} 'stuck', *khaa*^{low} 'galangal', *khaa*^{falling} 'kill', *khaa*^{high} 'trade', *khaa*^{rising} 'leg' (Abramson, 1997; Tingsabadh & Abramson, 1993).

The Thai writing system is derived from the Devanagari alphabet of India. It is one of only three non-Roman alphabets in the world that represent tones orthographically (cf. Burmese, Lao). Thai writing proceeds continuously from left to right without any spaces between words; they only occur at the end of an embedded or complete sentence. The alphabet is comprised of 44 letters (two are obsolete) representing 21 initial consonants – 14 obstruents (9 stops, 2 affricates, 3 fricatives), 7 sonorants (3 nasals, 2 liquids, 2 glides). A set of 17 binary orthographic features is required to distinguish the 42 consonant letters (Gandour & Potisuk, 1991). Thai has a high degree of consistency in mapping between phonemes and graphemes, but has multiple grapheme-to-phoneme correspondences for some consonants – 9 out of 14 obstruents, 3 out of 7 sonorants (Table 1, a–d) (see also Appendix A in Burnham et al., 2011; and in Winskel, 2010). Consonant letters are further subdivided into three classes (11 high, 9 middle, 24 low), reflecting old voicing distinctions that have been neutralized in modern Thai.

There are 23 vowel symbols plus various combinations thereof representing 18 monophthongs, 9 short and long, and 3 diphthongs. Vowels may occur in either horizontal or vertical orthographic position. Single vowel symbols are positioned before or after, above or below the consonant (see Table 1, e–h, respectively). Combinations of vowel symbols occur for diphthongs and triphthongs (see Table 1, i–k, respectively; cf. Appendix B in Winskel, 2010). Some vowels (/o/) are even represented implicitly as a sequence of consonant letters (Table 1, l). In spite of the complexity of the spelling of Thai vowels, they are relatively consistent in phoneme-to-grapheme mapping (Winskel, 2009).

Table 1
Characteristics of initial consonants, vowels, and tones in Thai orthography.

a. ถ ฐ ท ฑ ธ ฒ /t^h/	b. ส ศ ษ ซ /s/	c. ล ฬ /l/	d. ย ญ /j/	
e. โป	f. ป่า	g. ปี	h. ปู	
/poo/	/pàɑ/	/pii/	/puu/	
‘a game’	‘wild’	‘year’	‘crab’	
i. เมา	j. เมีย	k. เมื่อย	l. คน	
/mɑw/	/miɑ/	/mɯ̂ɑj/	/k^hon/	
‘drunk’	‘wife’	‘tired’	‘person’	
m. คา	n. ข่า	o. ข้า	p. เก๊	q. เก๋
/k^hɑɑ/	/k^hàɑ/	/k^hâɑ/	/kée/	/kěe/
‘cogon’	‘galangal’	‘servant’	‘fake’	‘chic’
r. ไซ้	s. ไส้	t. สิ้น	u. ซึ่ง	
/sɑ́j/	/sɑ̂j/	/sîn/	/sɯ̂ŋ/	
‘to dig’	‘intestines’	‘to end’	‘which’	

Note. Tonal diacritics using in phonemic transcriptions: mid (unmarked), low (ˋ), falling (ˆ), high (ˊ), rising (ˇ).

There are four tone markers representing the five tones; mid tone is unmarked (Table 1, m–q). All tone markers occur in vertical orthographic position above the consonant. They are always placed above the syllable-initial consonant or in the case of consonant sequences, above the second. If a vowel symbol co-occurs, the tone marker is written above the vowel (Table 1, t and u). Determining the tone of a syllable is complex. It depends on the class of the initial consonant, the type of syllable, the tone marker, and the length of the vowel (Table 2; cf. Table 2, Winskel & Iemwanthong, 2010). In addition, there are orthographic incongruities. The same tone marker leads to productions of different lexical tones (Table 1, r and s); conversely, the same lexical tone can be represented by different tone markers (Table 1, t and u). Based on a Thai word frequency database (Luksaneeyanawin, 2004), 53% of Thai monosyllabic words are intrinsically incongruent (Pattamadilok, Kolinsky, Luksaneeyanawin, & Morais, 2008). For example, the low tone marker produces a congruent low tone in both middle and high class consonants but an incongruent falling tone with a low class consonant (Table 2). Yet, most of these incongruities (69%) result from omission of a tone marker.

1.3. Current study

As aforementioned (Section 1.2), Thai is ideally suited for examining the interactions between phonological and orthographic representations because of orthographic differences in congruency

Table 2
Lexical tone production is determined by an interaction between tone marker, initial consonant class, and syllable type.

Tone marker		Syllable type									
		Smooth					Checked				
		Ø	◌่	◌้	◌๊	◌๋	Ø	◌่	◌้	◌๊	◌๋
Class of initial consonant	Mid	R	L	F	–	–	L	–	F	–	–
	High	M	L	F	H	R	L	–	F	H	–
	Low	M	F	H	–	–	H/F[a]	F	H	–	–

Note. A smooth syllable ends in a long vowel or a sonorant; a checked syllable ends in a stop. A hyphen indicates that the tone marker does not co-occur with that particular combination of consonant class and syllable type. Names of phonological tones: M, mid; L, low; F, falling; H, high; R, rising. Names of orthographic tone markers: Ø, mid (unmarked); ◌่, low (*eek*); ◌้, falling (*thoo*); ◌๊, high (*trii*); ◌๋, rising (*jattawa*). Those phonological tones underlined represent an inconsistency in the correspondence between tone productions and their orthographic tone markers.

[a] High tone occurs in checked syllables with short vowels; falling tone occurs in checked syllables with long vowels.

between the lexical tone and the tone marker. Using metalinguistic tasks requiring auditory recognition of Thai tones (tone monitoring, same/different tone judgment), adult native Thai speakers are found to perform better when the name of the phonological tone and orthographic tone marker are congruent leading to the same response than when they do not (Pattamadilok et al., 2008).

Similarly, oral reading is a complex learned skill that involves the interaction of orthographic, phonological, and semantic processes. Its neuroanatomical substrates are equally complex. Evidence from functional neuroimaging of normal readers and lesions associated with impaired reading converges on a widely distributed network including inferior frontal and temporoparietal regions implicated with phonological processing (see Cloutman, Newhart, Davis, Heidler-Gary, & Hillis, 2011, for review).

As far as we know, there are no linguistic analyses in the extant aphasia literature of oral reading performance by native speakers of a tone language with a non-Roman alphabetic orthography that includes tone markers. Such a writing system is ideally suited for examining the relative contribution of orthographic and phonological information of consonants, vowels, and tones when reading out loud. This paper represents the fourth in a series about a Thai patient with conduction aphasia (hereafter referred to as PK). In the case report, clinical signs, neuroanatomical evidence, and results from language examination were all consistent with a diagnosis of reproduction subtype of conduction aphasia (Gandour, Buckingham, Dardarananda, Stawathumrong, & Petty, 1982). Besides his poor performance on the repetition task, PK's ability to spell and read out loud was severely impaired. A detailed analysis of his spelling errors on a written picture naming task revealed that error rates were similar regardless of whether the orthographic unit represented a consonant, vowel, or tone (Gandour, Dardarananda, & Holasuit, 1991). In terms of error type, substitutions predominated in both consonant and vowel errors. The majority of tone errors, on the other hand, were secondary to changes in the syllable structure and/or class of the syllable-initial consonant letter. On an oral picture naming task, an analysis of sequences of phonemic approximations (*conduit d'approche*) revealed that tones were preserved better than consonants or vowels (Gandour et al., 1994). Tones were spared in 86% of PK's sequences. PK's pattern of output phonological disturbances in sensorimotor tasks across modalities is characteristic of a 'reproduction' subtype of conduction aphasia (Caramazza, Basili, Koller, & Berndt, 1981; Shallice & Warrington, 1977). PK's pattern of production deficits in speaking and writing led us to expect a breakdown in phonological encoding on an oral reading task. A detailed analysis and interpretation of PK's oral reading errors within the Hickok and Poeppel theoretical framework is presented, focusing especially on segmental (consonant, vowel) vs. suprasegmental (tone) elements of Thai phonology.

2. Method

2.1. Case history

The participant was a 55-year-old, left-handed, monolingual, male native speaker of Thai who had suffered a stroke nine years earlier than the present investigation. An EEG performed three days after the stroke showed a slow wave focus in the left temporal region. About 10 weeks after the stroke, a radioisotope brain scan showed uptake in the left posterior temporal region; a left-sided carotid angiogram revealed an infarct in the left temporoparietal region. At the time of this study, nine years post onset, PK was diagnosed with conduction aphasia based on clinical examination and the results of a Thai adaptation of the Boston Diagnostic Aphasia Examination (Gandour, 1981; Gandour, Dardarananda, Buckingham, & Viriyavejakul, 1986). His writing disorder was symptomatic of a dominant parietotemporal agraphia (see, Gandour et al., 1982, for further details of case history). PK's ability to read out loud was severely impaired, especially streams of text that spanned the length of a sentence. Most sentences he read out loud were replete with phonological, orthographic, and semantic paraphasias, often resulting in paragrammatic output. Before his stroke, he had completed 10 years of formal education, and later achieved the rank of 1st Lieutenant in the Thai Navy.

2.2. *Materials and procedure*

A set of elementary school readers were chosen to test the patient's oral reading ability including eight Aesop's fables and a few selections from an elementary school reader on Thai culture. By choosing beginning-level reading material, we were able to minimize lexical familiarity, encyclopedic knowledge, and syntactic complexity as potential sources of interference in his oral reading. He was simply instructed to read these passages aloud at his own pace. In some instances when he encountered inordinate difficulty with verbal self-correction, phonemic or semantic cues were eventually provided to maintain rapport. Data were collected over 16 separate sessions within a 3-week period in July 1980.

2.3. *Data analysis*

Only those oral reading errors were analyzed that could unambiguously be attributed to phonological *substitutions* involving onset (coda) consonants (C), vowel (V), and tone (T) or interactions thereof within a single syllable. Omission (296/1055 = 28%) or insertion (116/1055 = 11%) of whole words were excluded. Semantic errors (34/1055 = 3%) were eliminated because those attempts were aimed at different target words. Duplicate errors in pronunciation that occurred in a sequence of approximations to the same target word were dismissed as were perseverations of earlier responses which had occurred within the same reading selection.

Substitution errors accounted for over half of PK's phonological errors (609/1055 = 58%). They resulted (1) from a change to a single phonological element (C, V, T) or (2) from a change directly attributable to an interaction between elements. The former (1) consisted of the correct phonological response except for one error, either an incorrect consonant, vowel, or tone marker (n = 120). For example, ผูก /pʰùuk/ 'to tie' → ถูก /tʰùuk/ 'correct'; only the onset consonant was changed (cf. Sprenger-Charolles, Siegel, & Bonnet, 1998; Winskel & Iemwanthong, 2010). The consonant that was substituted was selected from the same consonant class (high). Therefore, there was no change in the tone produced. The latter (2) yielded two errors induced by a change in the class of the onset consonant: e.g., แพะ /pʰǽʔ/ 'goat' → แกะ /kæ̀ʔ/ 'to pick out'. Here, the target onset consonant belongs to the low class; the one that was substituted is a member of the middle class. This single change in consonant class results in the production of a different spoken tone (high to low). In contrast, ปาก /pàak/ 'mouth' → บอก /bɔ̀ɔk/ 'to tell' does not involve an interaction between elements. Though it involves two errors, the changes in the onset consonant and vowel are completely independent of one another.

3. Results

The distribution of phonological errors indicates that onset consonants were involved in the majority (58%) of substitutions (Table 3). In contrast, only 6% of errors involved coda consonants. Tones were implicated in 25% of substitution errors, over half of them (64%) involving an interaction with the syllable-initial consonant. Only 11% of errors implicated vowels. No errors involved an interaction between the vowel and either consonant or tone.

Table 3
Distribution of errors by phonological units and their interactions within syllables.

	Number[a]	Percentage
Consonant (onset)	69	58
Consonant (coda)	7	6
Vowel	14	11
Tone	4	3
Onset + tone	19	16
Coda + tone	7	6

[a] Total number of phonological errors = 120.

A phonological analysis of syllable-initial consonant errors revealed that 86% of onset errors resulted in the substitution of an oral stop or affricate (73%, 50/69) or nasal stop (13%, 9/69). Moreover, the target consonant was also a stop or affricate (87%, 60/69) (Table 4, a–e). Target consonants involving other manners of articulation were rare (Table 4, f and g).

Regarding tone errors, those that were independent of onset or coda consonants occurred infrequently; e.g., ที /t^{h}ii/ 'time' → ที่ /t^{h}îi/ 'place'. No discernible restrictions on the occurrence of tones were evident as a result of onset + tone errors. Almost all of the onset + tone errors (95%, 18/19) involved a change of manner of articulation (Table 4, h–k). As for syllable-final consonant errors, all substitutions conformed to distributional restrictions on Thai consonants: e.g., เจ็บ /tɕèp/ 'to be hurt' → เจ็ด /tɕèt/ 'seven'; ดอย /dɔɔj/ 'to tie' → ดอน /dɔɔn/ 'high ground'. Similarly, PK's coda + tone errors obeyed syllable coda constraints in Thai: e.g., ดิ้น /dîn/ 'to struggle' → ดิตถ์ /dìt/ 'a passage'; นอก /nɔ̂ɔk/ 'outside' → นอน /nɔɔn/ 'to recline'.

An orthographic analysis of syllable-initial consonant errors revealed that 57% (39/69) of the substitutions occurred within a Thai consonant class. Of those that occurred between consonant classes (43%, 30/69), the majority (60%, 18/30) resulted in a change to the middle class, i.e., those letters that represent unaspirated stops and affricates (cf. low class, 30%; high class, 10%). The onset + tone errors, on the other hand, rarely resulted in the substitution of a middle class consonant (Table 4, l). Instead, those errors (95%, 18/19) were triggered by substitution of consonants that represent other manners of articulation (nasal, fricative, approximant, aspirated stop or affricate), i.e., sounds that are represented by low and high class consonant letters (Table 4, h–k).

Table 4
Examples of PK's oral reading errors.

Onset	Onset + Tone
a. ใต้ /tâj/ 'below' → ได้ /dâj/ 'to be able to'	h. เขา /k^{h}ǎw/ 'they' → เรา /rɑw/ 'we'
b. ดับ /dàp/ 'to extinguish' → อับ /ʔàp/ 'fetid'	i. สู้ /sûu/ 'to oppose' → รู้ /rúu/ 'to understand'
c. เด็จ /dèt/ 'to be explicit' → เข็ด /k^{h}èt/ 'a skein'	j. วัน /wɑn/ 'day' → ฉัน /tɕ^{h}ǎn/ 'I'
d. ตรอง /trɔɔŋ/ 'to meditate' → กรอง /krɔɔŋ/ 'to sew'	k. แผ่ /p^{h}æ̀æ/ 'to spread out' → แม่ /mæ̂æ/ 'mother'
e. เมื่อ /mûɑ/ 'when' → เพื่อ /p^{h}ûɑ/ 'in order that'	l. ละ /láʔ/ 'to abandon' → จะ /tɕàʔ/ 'shall'
f. แย่ /jæ̂æ/ 'to be exhausted' → แน่ /næ̂æ/ 'certain'	
g. สุด /sùt/ 'to be finished' → ตุด /tùt/ 'a tray'	

To determine orthographic and phonological distances between target and substitution errors involving onset consonants, a set of binary phonological features was applied to classify the Thai consonant sounds, and a set of binary visual features to classify the Thai consonant letters (Gandour & Potisuk, 1991; cf. Moscicki & Tallal, 1981). PK's syllable-initial, consonant letter substitution errors ($n = 69$) were found to be primarily phonological in nature. The median phonological distance between the target consonant letter and its substitution was three features, whereas the median orthographic distance was four features. Of these consonant substitutions, 69% were based on three or fewer phonological features. In contrast, only 32% were based on three or fewer orthographic features. Results of a Wilcoxon matched pairs signed-rank test yielded a significant difference between phonological and visual distances from their respective targets ($S = -581$, $p < .0001$).

4. Discussion

In summary, PK's oral reading disturbances reveal systematic influences of phonology as well as Thai orthography. Syllable-initial consonant errors were predominant. Fewer errors occurred with vowels and tones. Of tone errors, most were secondary to substitutions involving consonants. Phonologically, target consonants were either stops or affricates; substitutions were also stops or affricates, or nasals. Orthographically, within-class consonant errors were more frequent than between-class. Of the latter error type, the majority resulted in a change to middle-class consonant letters, those representing unaspirated stops and affricates. In contrast, tone errors triggered by onset consonant substitutions almost invariably involved a change to low- or high-class consonant letters: low-class representing aspirated stops, affricates, fricatives, nasals, liquids, and glides; high-class representing aspirated stops, affricates, and fricatives. An analysis of consonant errors further shows that the distance between target and substitution is smaller for phonological than orthographic features, emphasizing the phonological nature of PK's errors in reading aloud.

4.1. Conduction aphasia represents a disruption of the sensorimotor interface system

The breakdown in phonological encoding observed in PK's oral reading of Thai script may be attributed to cortical damage to an area in the left hemisphere located in the Sylvian fissure at the temporoparietal boundary (Spt, Sylvian–parietal–temporal; Hickok & Poeppel, 2007; Fig. 1, p. 395). PK's lesion site overlaps this area. Based on EEG waves, radioisotope brain scan, and left-sided carotid angiogram, his lesion was circumscribed to the left posterior temporal and temporoparietal regions.

As part of a sensorimotor dorsal stream, Spt maps sensory or phonological representations onto speech motor representations. Spt is functionally related to inferior frontal motor speech areas (Buchsbaum, Hickok, & Humphries, 2001). Spt itself is multisensory; it is not part of unimodal auditory cortex (Okada & Hickok, 2009). Visual feature analysis and early orthographic processing are well-known to be associated with occipital and occipital–temporal regions. We interpret PK's impaired performance on an oral reading task as evidence in support of the functional role of Spt, i.e., converting phonological representations derived from visual input into articulatory motor representations for speech output. An analysis of PK's consonant letter substitutions on the basis of phonological and visual similarity supports this interpretation. As measured by the distance between the target and substituted letter, PK's reading errors were primarily phonological in nature as were his writing errors (Gandour et al., 1991).

If conduction aphasia involves a disruption of the sensorimotor interface system, then it is likely that phonological encoding of segmental and suprasegmental elements may be differentially disrupted depending on the sensory modality of the task. Indeed, the extent to which PK's consonants, vowels, and tones are disrupted varies depending on the specific task. In the current study of oral reading, consonant errors predominated as compared to either vowels or tones (C > V, T). In oral confrontation naming of pictures, tones were well-preserved (86%) in sequences of phonemic approximations; consonants and vowels were more vulnerable to disruption (C, V > T; Gandour et al., 1994). In written confrontation naming of pictures, spelling error rates did not differ between phonological elements (C = V = T; Gandour et al., 1991). Thus, it appears that PK's tonal errors occur less frequently than consonant errors only when he is required to produce a spoken response as in oral picture naming and reading aloud tasks.

This disparity in error rates of PK in reading (aloud) and writing can largely be explained by a functional deficit in his ability to encode phonological information specifically for speech production. But there are specific characteristics of Thai orthography that may also play a role in differences in the pattern of errors among consonants, vowels, and tones. As pointed out by (Burnham, Luksaneeyanawin, Kantamphan, & Reid, in press), when spelling a Thai word aloud, the tone marker is named last; when writing a Thai word, the tone marker is the last component added within a syllable. Though tones are marked consistently in the Thai writing system, there are in fact more Thai words without a tone marker than with. In adult (silent) reading of Thai words in sentences (Winskel, 2011), it has been shown that tone markers, along with onset consonants are processed earlier than others. Similarly, tone takes a secondary role to consonants and vowels for young children learning to read Thai (Winskel & Iemwanthong, 2010). Such facts about Thai orthography and reading development cannot be dismissed out of hand. Indeed, PK's output is consistent with them. Most of his tonal errors were secondary to substitution of the onset consonant. It has already been pointed out that task mechanisms are dependent, in part, on a specific modality (e.g., visual analysis of orthography in reading) or dependent on the effects of processing opportunities within a specific task (e.g., multiple looks at words in reading out loud) (Caramazza, Miceli, & Villa, 1986). Such variation in PK's error rates between articulatory motor (oral reading) and manual motor (written spelling) tasks is precisely what one would predict if his functional deficit is an inability to encode phonological information for *speech* production.

Saccadic eye movements have also been used to assess the relative contribution of phonological and orthographic information of consonants, vowels, and tones in word recognition when reading Thai *silently* [emphasis added] (Winskel, 2011). Results from parafoveal processing indicate that orthographic information plays a more prominent role than phonological information for tonal as well as segmental elements in *early* stages of lexical access. However, this task imposes considerable demands on memory and attention in the absence of time constraints. The effects we observe in PK's oral reading are therefore likely to reflect a *later* stage of word processing in which phonological information predominates as the orthographic stimulus is converted to an articulatory code for speech output. Such findings converge with lesion overlap maps from acute stroke patients that point to inferior temporoparietal regions as key areas for phonological processing in oral reading (Cloutman et al., 2011).

PK's educational level, occupational status, and metalinguistic observations about consonants, vowels, and tones after his stroke indicate that his premorbid level of reading proficiency clearly falls within the normal range (cf. Burnham et al., 2011). Thus, any observed reading deficits can be attributed to damage in the left posterior temporoparietal region.

4.2. Error rates for phonological elements are driven primarily by major disruption to the onset component of the syllable

Tones are generally considered to be represented on a suprasegmental tier independent of those for consonants and vowels (Yip, 2002). Phonologically, tones are assigned to the syllable which includes onset and rhyme components. Consonants are assigned to syllable onset; vowels and syllable-final consonants, respectively, to the nucleus and coda of the rhyme component.

The majority of PK's phonological errors involved syllable-initial consonants. Both the intended target and its substitution were either stops or affricates in the overwhelming majority of errors. In contrast, there are comparatively few vowel errors. None involved an interaction between the vowel and the consonant. PK's errors appear to reflect a differential sensitivity to the onset as compared to the rhyme component of the syllable. This interpretation is consistent with a cross-sectional study of Thai spelling proficiency in which consonant errors predominated followed in turn by vowel and tone errors (Burnham et al., in press).

The major contribution of syllable-initial consonants, however, cannot be attributed simply to the letter position within a word (see Winskel, 2011, for review, pp. 741–743). Though Thai has an alphabetic script, the ordering of letters and diacritics does not necessarily correspond to the ordering of phonemes. Vowel symbols can be written nonlinearly above or below the consonant, to either side of the consonant, both before and after the consonant, or combined before, above, and after the consonant (Table 1, a–k). There are four vertical levels in Thai script (-1, 0, 1, 2); level 0 represents the main line of writing (Burnham & Mattock, 2007, p. 270). In terms of vertical orthographic position, some vowel symbols may be placed below (level -1) or above (level 1) the consonant (Table 1, g and h). Thus, it is unlikely that marked differences in error rates between consonants and vowels can be attributed to symbol position. Letter transposition research also suggests that consonants and vowels are not distinguished until a *later* stage of phonological processing (Johnson, Perea, & Rayner, 2007; Perea & Peretz, 2009; Winskel, 2011).

Of the tone errors, over half of them involved an interaction with the consonant onset (Table 4, h–l). Almost all of these errors resulted in a change of manner of articulation of the consonant, i.e., sounds represented by low and high class consonant letters. No errors resulted from an interaction between the vowel and tone. In Thai script, tone markers are placed above the syllable onset (level 1), i.e., over the singleton consonant or the second consonant (in bold) in case of a cluster (e.g., ขว้าง /kʰ**w**âɑŋ/ ‘to hurl’). Vowel symbols, however, may also occur vertically above the syllable-initial consonant. In those instances, the tone marker is positioned on level 2 above the vowel symbol (Table 1, t and u). Thus, any observed differences in error rates between vowels and tones cannot be attributed to orthographic position only. Tone errors independent of onset or coda consonants were rare. This finding is in agreement with PK's performance on a picture naming task in which he was also required to produce a spoken response (Gandour et al., 1994).

In spite of overlapping vertical orthographic positions, error rates were markedly higher for consonants relative to either tones or vowels. The source of the disruption, however, cannot be reduced to a phonological distinction between segmental and suprasegmental elements. Vowels are segmental; tones are suprasegmental. It is hypothesized that syllable-initial consonants are first placed in the onset position; vowels next in the rhyme; and tones then assigned to the whole syllable. Tonal errors are then seen to be a secondary consequence of errors in selection of the syllable-initial consonant.

Are unique characteristics of Thai orthography responsible for the predominance of errors involving syllable-initial consonants? Thai has characteristics of syllabic as well as alphabetic writing systems. In addition to nonlinear expressions of vowels and tones, and misaligned vowels, it has implicit vowels for consonants (in bold) (e.g., **พ**ยางค ์ /**pʰɑ**jɑɑŋ/ ‘syllable’). Consonants, on the other hand, always occur along the main line of text. They are written in linear order; vowels, in linear or nonlinear order; and tones, in nonlinear order placed above the syllable-initial consonant. In terms of linear order, contrary to fact, one would expect consonants to be more resistant to disruption than vowels and tones. Though vowels are more complex graphemically than consonants, their grapheme-to-phoneme correspondence rules are more consistent than those for syllable-initial consonants. Tone rules, on the other hand, are complex as they depend on the class of the initial consonant (low, mid, high), the type of syllable (open, closed), the tone marker, and the length (short, long) of the vowel. Thus, in terms of complexity of grapheme-to-phoneme rules, vowels, but not tones, are expected to be better preserved than consonants. Yet tones are also less vulnerable to disruption than consonants. This disparity in rate and type of error between tones and consonants cannot be attributed to word position. All tone markers occur in vertical orthographic position *above* the syllable-initial consonant. The fact that most tone errors are a secondary consequence of consonant substitutions further reinforces the preeminent role of onset consonants in Thai reading. These findings combined suggest that PK's oral reading impairment involves a complex interaction between phonological and orthographic representations.

5. Conclusion

Oral reading entails visual analysis of an orthographic code, conversion to a phonological code, and then to an articulatory code for speech motor output. On an oral reading task, the impaired performance of a Thai patient with conduction aphasia is shown to reflect primarily a breakdown in phonological encoding. His lesion site in the left posterior temporoparietal zone overlaps the location of a sensorimotor interface system in which sensory or phonological representations are mapped onto speech motor representations. Differences in rates and types of errors among consonants, vowels, and tones suggest that this visual-articulatory interface reflects the influence of Thai phonology as well as peculiar characteristics of its orthography.

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