Neural organisation and writing systems

by

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My aim in this paper is to suggest ways in which knowledge of the brain structures used in reading may help our understanding of literacy skills and why some people have trouble acquiring them. I start with an unusual question: to what extent does brain organisation reflect the social practices of reading? That is to say, to what extent is the the neural substrate of reading determined by the kind of writing system that the child acquires? My question make strike you as unusual since. on the one hand, it is trivial that all differences in experience will lead to differences in neural substrate, and on the other, these difference can scarcely be systematic, and hence interesting. To begin with, there will be enormously different learning experiences associated even with the acquisition of a single writing system. Secondly, reading and writing cannot be the kinds of things that specific neural systems have evolved to deal with: in evolutionary terms, there has not been enough time for selective pressures to have done their work. Moreover, if we had been endowed special reading and writing bits of the brain - as Chomsky (1972) has claimed we are endowed with special language bits - then one would have expected, perhaps, that writing systems should all follow the same pattern. However, most scholars agree that there are at least four, and probably six, independent orthographic traditions based on distinct ways of representing the spoken language. (Gelb, 1963; Mattingly, 1992) (1. Mesopotamian cuneiform; 2. Cretan, including Linear B; 3. Chinese; 4. Mayan; 5. Egyptian; 6. West Semitic - Phoenician, Hebrew, Greek, Roman.) These facts make the study of the neural substrate of reading very different from, and apparently less rewarding than, the study of, for example, visual processes, where there is a clear evolutionary line of development of a system whose structure is tightly linked to its function.

I shall use the term "writing system" in Sampson's (1985) sense of a set of graphemic units used to represent a language, not the graphemic units themselves, which he calls the "script". Thus, English and Italian use largely (but not completely) the same script - the Roman alphabet - but uses the graphemes in the set in different ways to represent the their respective languages.

Any writing system involves three mappings: between graphemic units and sounds; between graphemic units and meanings; and, this must not be forgotten, between meanings and sounds. This triangular arrangement is represented in Figure 1, where G stands for graphemic units, S stands for sounds and M stands for meanings.

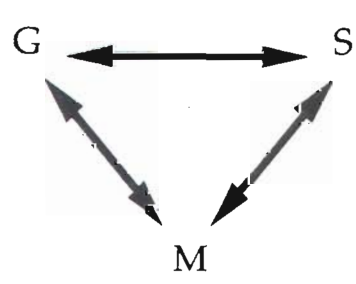


FIGURE 1

Different writing systems use different unit types, and different mappings between the types. In the English writing system, letters are the basic unit type, and these are mapped in a rather inconsistent way onto phoneme sound units, as a rule. In the Italian writing system, letters are mapped in a more regular way onto phonemes, and phonemes onto letters. It is not quite true than there is a one-to-one mapping between letters and sounds (t <-> /t/, b <-> /b/; s<->/s/ or /ʃ/ depending on context; g <-> /g/ or /d*/ or /lj/ depending on context), but there is almost a one-to-one mapping between graphemes and phonemes (sc <-> /ʃ/; ga, go, gu <-> /g-/; gli <-> /lj-/). Moreover, different words in Italian or English are generally distinct in their sounds, with a small number of well-known exceptions (see below). Thus, for these languages, using alphabetic scripts, therefore, the route from graphemic units to meaning could plausibly go via sound - G -> S -> M - since once the reader has worked out that the string HINT is pronounced "hint", the meaning will be clear providing of course the word was already a part of the reader's spoken vocabulary.

In Chinese Hanzi, or in Japanese Kanji, the smallest graphemic unit, the Hanzi or Kanji, character is mapped onto a whole syllable, and this syllable is a meaningful unit in itself - a word or a morpheme. Now Hanzi or Kanji both map languages that have very small inventories of syllables. In Mandarin Chinese, the national standard language, there are some 1307 syllables (taking into account tones). Japanese there are just 47 basic syllables (strictly, "mora"), and only about 110 including those diacritically marked. However, there are very large inventories of characters: some 50,000 Hanzi, with 3000 in common use; and 50,000 Kanji, with 2500 on the recently officially prescribed list of Jyoyo Kanji, which newspapers and government documents should be restricted to. This means that, unlike European writing systems, each sound unit is mapped onto many, many graphemic units and many, many meanings. The following example in Table 1 from Mandarin Chinese illustrates the point:

USEFULNESS OF SOUND IN DERIVING MEANING IN CHINESE

sound: **bù**

NO	不	PLACE-NAME	吥
PLUTONIUM	钚	CLOTH	布
FEAR	怖	BOOK	薄
PLACE-NAME	𡊄	STEP	步
VASE	瓿	PART	部
WHARF	埠	BASKET	篰
PLACE-NAME	埔		

TABLE 1

Now it is clear that writing systems use different inventories of graphemic units, indeed inventories of different kinds of unit - corresponding to sublexical sound units, or to more word like units. Now, of course, it has been frequently pointed out that mappings from letters to sounds operate at two levels at least: at the level of individual grapheme units - letters, in English - and at whole word levels, and possibly intermediate levels. Clearly, a whole word mapping is necessary in English to achieve the correct pronunciation of many words. This means that the mappings in Figure 1 have to be supplemented by a mapping that utilizes the reader's knowledge of lexical items, denoted by the letter "L" in Figure 2.

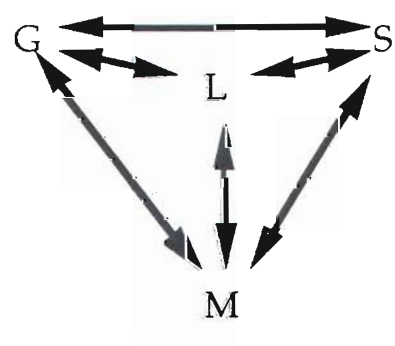


FIGURE 2

In addition to units of different types - phonemes, syllables, words - we can distinguish types of *mapping relation* of graphemic unit onto sounds:
A mapping is *consistent* if the graphemic unit always maps on to the same sound. It is inconsistent if it maps on to more than one sound.

Given that there may be more than one level at which the mapping can happen, then an inconsistent mapping is said to *congruent*,in a particular word, if mappings at all levels yield the same sound for the unit. It is incongruent if it does not.

For example, the letter D is always pronounced /d/ in English, I think. It therefore has a consistent mapping, and ipso facto, it will be pronounced /d/ whatever word it appears in. B, on the other hand is inconsistent, since in some words, like *limb, crumb,* it is silent. Now it may be possible to construct a nonlexical level of representation for the sequence, specifying a contextual rule that does have a consistent mapping. A rule such as -MB- -> /m/ will not suffice, because of words like *ambit,* but a rule such as -MB# -> /m/ probably will. However, as is well-known, there are letters in English like G whose pronunciation is determined by the word in which it appears. There seems to be no rule that captures the pattern: compare *lager* with *larger,* not to mention *rough* and *bough*. Given that -GE is usually pronounced /dʒ/, the -GE is incongruent in *lager,* but congruent in *larger.*

The question I want to pose in this paper is the extent to which neural organisation of reading is shaped by these mapping properties of the writing system. Will all the mappings shown in Figure 2 be utilized by the readers of widely different writing systems, or utilized to the same extent by readers of different writing systems?

Now Katz and Feldman (1981) some time ago argued that reading processes are shaped by what they call "orthographic depth." This will determine how the reader carries out lexical access.

> The kind of code used for lexical access depends on the kind of alphabetic orthography facing the reader. Specifically, it depends on how directly the orthography reflects the phonetic surface. Languages [they mean writing systems] in which the spelling-to-sound correspondences are simple and invariant (as in Serbo-Croatian) will readily support information-processing structures for reading that utilize the language's [writing system's] surface phonological features. On the other hand, in an orthography that bears a complex relation to speech (a deep orthography such as English), phonologically structured mechanisms for processing words will be less developed. (1981, pp. 85-86)

What they meant by this was that Serbo-Croatian readers would rely on processes involving mappings from letters to phonemes (G->S) to achieve lexical access and hence meaning. They would not use the mapping G->L, but rather G->S->L.

Now Katz and Feldman's idea of "simple and invariant" correspondences does not make the distinction between consistency and congruency, nor between the levels at which these correspondences can occur. Therefore, they really have no account of character-based writing systems like Chinese or Japanese Kana syllabary, where there is clearly invariance in mappings from G->S - the same character is always pronounced in the same way. However, this way is not predictable on the basis of grapheme-sound rules (unless one rule per character is allowed).

The orthographic depth hypothesis has been extensively tested on normal adult subjects, with conflicting results. One of the key problems is the finding of lexicality effects in reading aloud words written in shallow orthographies. That is, effects that depend on a sequence of graphemes being an identifiable word - for example, word frequency effects, and the effects of preceding the target word with a word that is related to it meaning, or is an associate of it (like DOCTOR-NURSE, DOCTOR-HOSPITAL). It has been repeatedly demonstrated that this manipulation, called "priming", facilitates and speeds naming of the target word. Baluch and Besner (1991) showed that Persian readers, under some circumstances, would name Farsi words (with vowels marked) more quickly when the words were frequent, and when they were primed by preceding words (i. Now if the readers were operating solely with the sublexical mappings this should not have occurred. Similar results have been found for Spanish (Sebastián-Gallés, 1991) and Italian (Tabossi & Laghi, 1992). More worrying for the orthographic depth hypothesis, are related findings that the presence or absence of lexicality effects depends on whether or not the task involves the reading of *non-words*. In all the studies mentioned here, lexicality effects disappear when non-words are in the target list. Besner and Smith (1992) argue the presence of non-words induces subjects to adopt the strategy of reading by the sublexical process using the G->S mappings which can be applied to both words and nonwords, while, obviously, the whole word route only applies to words. This kind of strategic manipulation of lexicality effects has even been found in Japanese (Wydell, 1991).

Clearly, these results pose serious problems for the orthographic depth hypothesis. They also pose problems if we are seeking to establish how many processes for getting from print to sound in the heads of the reader. If the behavioural results seem to depend critically on strategy - here determined by the composition of experimental lists - how can we be sure that the strategy has not been specially devised for the experiment, and is not part of the usual apparatus used in everyday reading?

Our way of answering this is to look at the neuropsychology of reading. We can, in general, tell from neuropsychological studies of higher cortical functions in brain-damaged patients that very specific functions can be impaired - or spared - indicating that these are supported by highly specialised neural structures. By studying a range of relevant patients, it is sometimes possible to discover from the pattern of imparied and spared functions, the cognitive architecture into which the compoent functions fit. If a function has been seriously damaged, then patients' strategies cannot restore it, in general, though some compensatory processes may be invoked or developed. Suppose, for example, that an English reader, following brain damage, can no longer make use of his knowledge of the whole word mappings, G -> L. He should be poor at reading irregularly speled words, whatever the task. No list manipulation, apart from excluding irregular words should make any difference.

The question I want to raise is this: to what extent are the components and their interrelations determined by experience? In particular, to what extent are they determined by what the brain has to learn about the social practices in which it develops? Will you get different components or different relations between the components if these experiences are different.

For example, in the China they have three common ways of writing the numbers - two of which are characters that denote numbers just like our arabic numerals, but can also be read as words, like writing FOUR for 4. Japanese use the same characters as the simpler of the two Chinese sets. The next figure, I have listed these characters and their pronunciations in the two languages. The Chinese and Japanese characters correspond exactly to the spoken forms, just FOUR THOUSAND ONE HUNDRED AND SIXTY FOUR corresponds word for word with the spoken form, "four thousand one hundred and sixty four", while 4164 does not. A complex transformation is needed, which, among other things assigns quite distinct interpretations to the two 4s. (Note that a different transformation would be needed to read 4164 as part of a British telephone number ("four one six four"), and a third as a French telephone number ("quarante-et-un soixante quatre").

FIGURE 3: WRITING NUMBERS IN JAPANESE, CHINESE AND ARABIC NUMERALS

	Chinese Character/ Kanji Character	Japanese Reading	Chinese Reading
1	一	ichi	yī
2	二	ni	èr
3	三	san	sān
4	四	shi	sì
5	五	go	wǔ
6	六	roku	liù
7	七	shichi	qī
8	八	hachi	bā
9	九	kyu	jiǔ
10	十	jyu	shí
15	十五	jyu go	shí wǔ
18	十八	jyu hachi	shí bā
20	二十	ni jyu	èr shí
31	三十一	san jyu ichi	sān shí yī
100	百	hyaku	(yī) bǎi
221	二百二十一	ni hyaku ni jyu ichi	èr bǎi èr shí yī
536	五百三十六	go hyaku san jyu roku	wǔ bǎi sān shí liù
1.000	千	sen	(yī) qiān
5.529	五千五百二十九	go sen go hyaku ni jyu kyu	wǔ qiān wǔ bǎi èr shí jiǔ
10.000	万	man	(yī) wàn

How does this affect the neural organisation of number reading processes? Now, the transparency of the character form with respect to speech may facilitate number naming. That is to say, the processes required to turn the characters into spoken words will be simpler than with the arabic numerals. Ther reader need not figure out that the first four needs to be spoken as sì qian, rather than just sì. However, carrying out arithmetic with characters may be impeded if the mental representation of numbers used for calculation is more like our familiar arabic place notation. So the permanent organisation of reading numbers may involve two quite separate systems that converge on the spoken number names, while arithmetical operations (addition at least) may involve two transformational processes that converge on common representational format, but one different from the spoken names.

To explore this we tested normal Chinese and Japanese subjects on two tasks. The first was a speeded naming task. In this they saw numbers on the screen, presented in one condition as characters and in the other as arabic numerals. (Chinese subjects also saw numbers as a third script, which is visually more complex and is nowadays used mainly for financial dealings. Only the characters for the numbers 1 to 3 are presently used in Japan). The task was simply to name the numbers as quickly as possible. In the second task, the same subjects carried out a simple addition. Two single digit numbers with the addition symbol were presented either as characters or as arabic numerals. The subject simply had to say the answer as quickly as possible.

Our findings were straightforward. Overall, subjects named numbers quicker when they were characters. The difference, as one might expect, was found for the larger numbers rather than for the single digit numbers, where the two scripts were equally transparent. This is particularly apparent in Japanese, where the overall difference just failed to reach significance, but was very marked for the larger numbers. See Table 2

CHINESE

	ARABIC RT	(%errors)	CHARACTERS RT	(%errors)
NAMING (N=54, N=54))	1039	(6)	935*	(7)
ADDITION (N=16, N=16)	900*	(2)	1012	(4)

JAPANESE

NAMING (N=52, N=52))	713	(5)	724	(2)
ADDITION (N=16, N=16)	865*	(3)	1087	(6)

*: presentation in this mode significantly quicker than in the other presentation mode ($p<0.05$)

TABLE 2: NAMING AND ARITHMETIC IN CHINESE AND JAPANESE: ARABIC NUMERALS vs CHARACTERS
(adapted from Butterworth, Yin, Wydell & Cipolotti, forthcoming)

Of course we cannot be sure that these findings are not the consequence of some special strategies designed by our subjects for precisely the tasks at hand. We need rather to find out if the hypothesisd componentsshow selective break down in patients; and to discover the effects of experience, we would need to see whether the same patterns of breakdown are found in Chinese, Japanese and English patients. It would also be interesting to see if learning to calculate using an abacus create a different components, or a different arrangement of components than learning by traditional Western methods? It would take us too far from our present concerns to review the evidence on this here, but we have recently found that for European patients, number reading can be impaired while calculation is spared, and also the reverse pattern has been noted. Also there is a double dissociation between reading arabic numerals and reading letters and words. The relevant studies have not been carried out for Chinese and Japanese patients. (See Cipolotti, 1993, for a review and data).

Let us return to the mappings used by the English writing system. I wish to draw attention to three of its main properties.

THE ENGLISH WRITING SYSTEM
1. Elements (letters) stand for meaningless speech sounds (phonemes) in a more or less systematic way
eg. D -> /d/; I -> /I/; M -> /m/; N -> /n/ ; T -> /t/
2. Letters and sounds can be assembled to form syllables and words
3. Letters can be combined in new ways to make new syllables
eg. FREON®, YOMP

TABLE 3

1. A small number of elements (that is the letters) stand for speech sounds that are meaningless, and often unpronounceable, on their own.

LETTER-SOUND CORRESPONDENCES
"PHONICS"

B	->	/b/	L	->	/l/
D	->	/d/	M	->	/m/
F	->	/f/	N	->	/n/
G	->	/g/	P	->	/p/
H	->	/h/	R	->	/r/
I	->	/i/	T	->	/t/
K	->	/k/	W	->	/w/

TABLE 4

These are some of the letter-sound correspondence rules for English. The letter is on the left of the arrow its pronunciation on the right. The consonants can really only be pronounced with the addition of a vowel, like bɪ dɪ etc. I have listed just one vowel for simplicity.

2. Letters and hence phonemes can be assembled to form syllables and words. That is the point of an alphabetic system: a small number of elements, readily learned, can be used in various combinations and permutations to make up all the words in the language. You don't have to invent new elements. From the assembled sounds you can fairly reliably derive the meaning. HINT - a slight indication.

3. And hence, you can use new permutations of letters to spell new words. Like these.

ZINT, YIND

Using the rules, you read those novel strings with no trouble, probably as /zɪnt/ and /yɪnd/. This ability to map elements onto sounds is the basis of "phonics". As many of you will know, the British government is very keen on children being able to spell correctly. They are also very keen to make phonics basis of teaching reading in schools, rather than the progressive "look-and-say" method. The idea seems to be that once you have mastered the *discipline* of a few basic rules, like those I presented, you can read all the words, pretty well, that are composed by them. Like these:

DINT, FLINT, HINT, LINT, MINT, PINT, TINT.

Or these:

BIND, FIND, GRIND, HIND, KIND, MIND, RIND, WIND.

Well, it is clear, as I mentioned earlier, that readers of English need to have a way of recognising words as a whole, so as to deal with the irregular spellings of many English words. (In this, as in so many things, our government thinking is confused: they want phonics taught. They want to improve spelling. They think teaching phonics will improve spelling. The thinking is confused because it is not based on research, but on ... the words that spring to mind are "blind prejudice.")

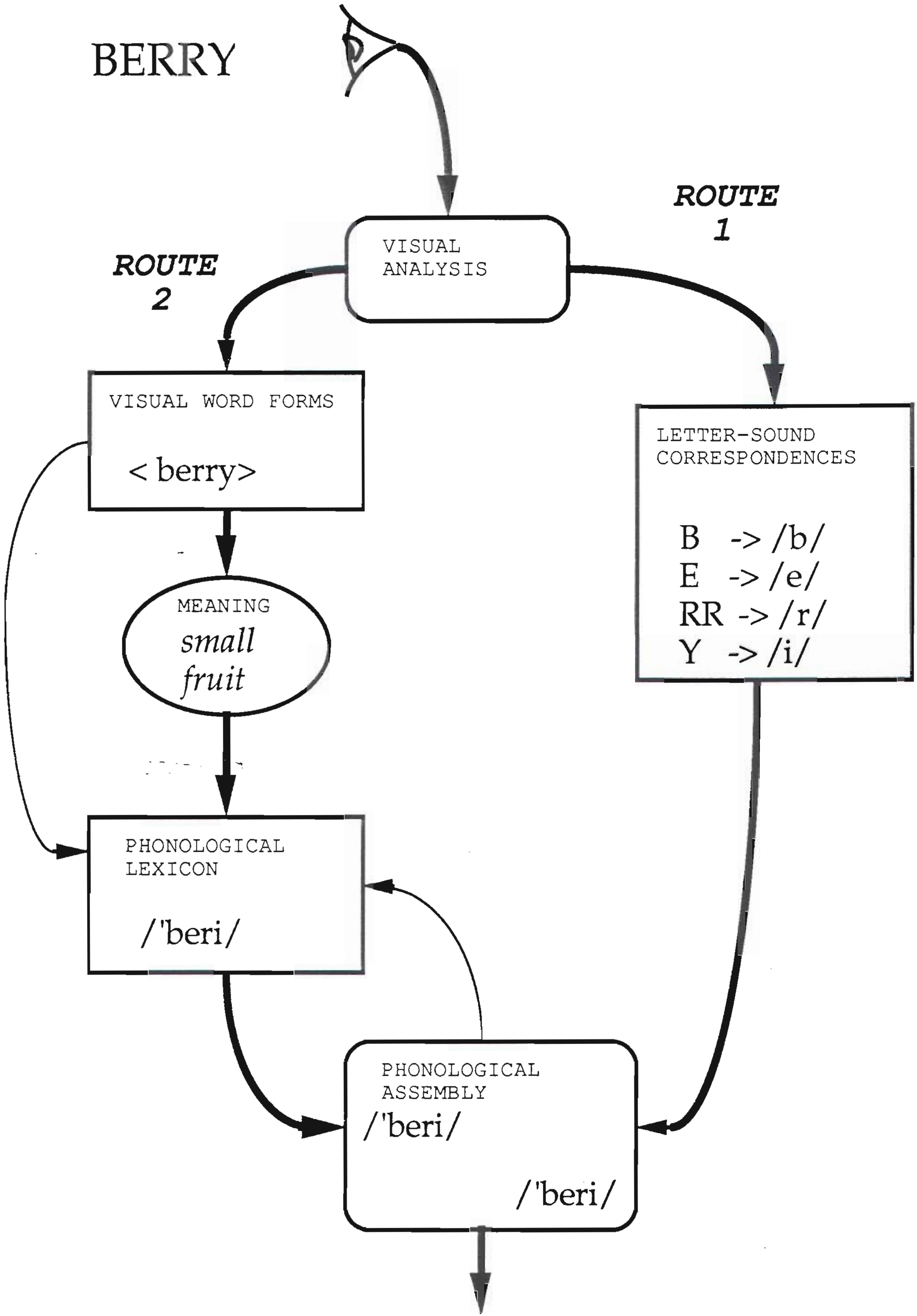
Clearly, it is possible to read all words, and to spell them correctly, by learning each letter string off by heart. But of course some procedure for mapping letters onto sounds will be helpful for reading letter strings not previously encountered.

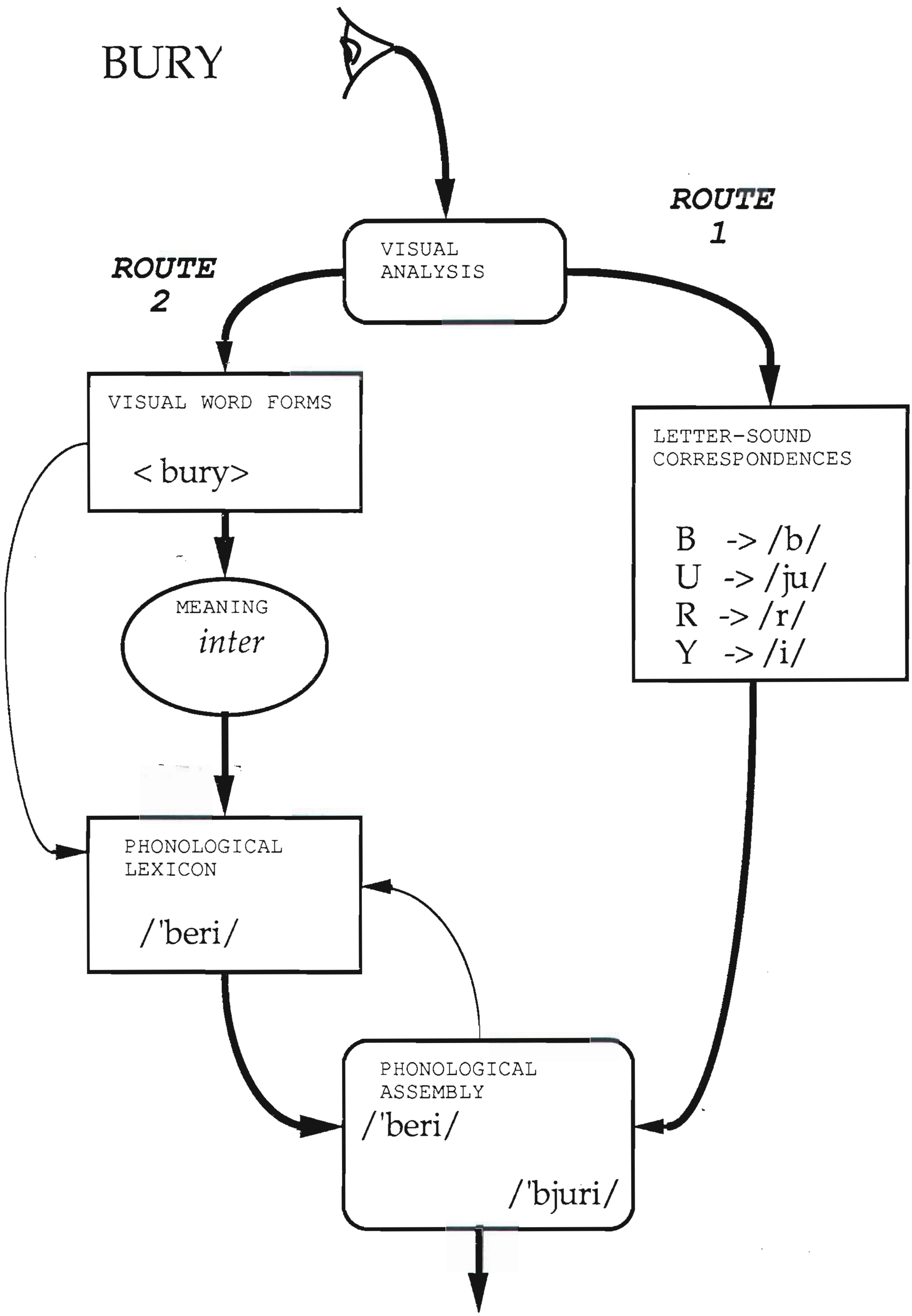
It is now widely, though not universally, believed that skilled adult readers of English deploy two "routes" in reading (Patterson, 1981). There is a route that uses word *elements,* Route 1 in Figure 4 below. This route depends on assembling the pronunciation of each element to produce the pronunciation of the whole word, and only via this pronunciation, access the word's meaning. Patterson calls this the "assembled route".

There is a whole word route, Route 2, which makes use of learned patterns of letters - "visual word forms". These can be mapped directly on to word meanings and to the pronunciation of the whole word.
Where the word has a regular spelling there is congruence between the output of both routes - as in BERRY. Patterson calls this the "addressed route".

Where the spelling is not regular, there is conflict. If the reader relied on Route 2, the sound /bjuri/ would be assembled. and this doesn't correspond to a word. Now the reader does not know whether the string is regular or irregular before he starts, so it is assumed that both routes are deployed simultaneously. For common words the whole word route is likely to be quicker, for uncommon words the part-word route is likely to be quicker. And it has been found that broadly the regularity of spelling helps the reading of the less frequent words.

The architecture of the two routes and how they operate with congruent and incongruent words is shown in Figures 3 and 4.


BERRY
ROUTE 1
ROUTE 2
VISUAL ANALYSIS
VISUAL WORD FORMS
< berry>
MEANING
small fruit
LETTER-SOUND CORRESPONDENCES
B -> /b/
E -> /e/
RR -> /r/
Y -> /i/
PHONOLOGICAL LEXICON
/'beri/
PHONOLOGICAL ASSEMBLY
/'beri/
/'beri/


BURY
ROUTE 1
ROUTE 2
VISUAL ANALYSIS
VISUAL WORD FORMS
< bury>
LETTER-SOUND CORRESPONDENCES
B -> /b/
U -> /ju/
R -> /r/
Y -> /i/
MEANING
inter
PHONOLOGICAL LEXICON
/'beri/
PHONOLOGICAL ASSEMBLY
/'beri/
/'bjuri/

Now if these two routes are reflected in permanent neural organisation, as opposed to being strategies that can be put together as needed, then one route might be impaired in one patients, the other in another - with predictable consequences

TWO ROUTES FOR MAPPING GRAPHEMES ONTO PHONOLOGY

	NORMAL FUNCTION	SYMPTOMS WHEN DAMAGED	DISORDER
ROUTE 1	letter-sound mapping	•new words not readable •no regularity effects •no regularisation errors •semantic errors	"phonological dyslexia" "deep dyslexia"
ROUTE 2	whole-word reading	•new words readable •regularity effects •regularisation errors	"surface dyslexia"

TABLE 5

You might think that this dual route architecture is demanded by the peculiar nature of English spelling, and it is this that sets up two neurally separable subcomponents in the brain. Writing systems that did not have this mix of regular and irregular mappings should not show a dual route architecture. We should not find it in the brain of readers of Spanish, Serbo-Croatian, Korean HanGul, that use only consistent mappings between letters and sounds. However there is suggestions that even readers of these orthographies might have neurally distinct routes of the right kind. One patient studied by Masterson, Coltheart and Meara (1985) was able to read accurately and fluently, but when confronted by homophones (possible in Spanish, since one phoneme may be represented by more than one grapheme) showed far more confusions as to their meanings than would be expected of normal readers. This suggests that the patient's letter-sound route was working, but his whole word route was not. It must be admitted that neuropsychological data for two routes in highly consistent orthographies has been slow in coming.

If shallow alphabetic orthographies, pose one sort of problem for our approach, then writing systems that don't use letters at all - like Chinese - should pose even more of a problem.

The Chinese system is very different from English.
Far from there being a small number of letters, there are some 50,000 characters, with at least 3000 required for everyday use. These elements, unlike letters, do not stand for sounds that are meaningful only in combination. Each character stands for a syllable, and each syllable is a word (or a meaningful morpheme).

THE CHINESE WRITING SYSTEM

1. Elements (characters) stand for meaningful speech sounds (single syllable morphemes) in an unsystematic way

2. Elements and sounds can be assembled to form words

3. Elements cannot combined in new ways to make new syllables.
There are fewer than 1500 syllables in Mandarin, and that's it!

TABLE 6

In English, there are limitless new syllables that could be constructed to make a new word. In Chinese fewer than 1500 syllables are permitted. This means that each syllable has to do duty in many words.

This also means that deriving the sound from the writing is a poor guide to the meaning, as we saw above in the case of bù Unlike English where it's usually one sound one meaning, or set of related meanings; homophones (BEAR-BARE; TOE-TOW) are the exception rather than the rule. Yin (1991) has calculated that each syllable is associated with a mean of some 7.8 characters found in the prinicpal distionary, each with a distinct meaning, though he notes there are 255 syllables represented by just one character each.

This is a very different social practice from English. However, a closer inspection reveals *some* similarities. Yin has further calculated that about 80% of characters are "pictophonetic". These characters are not just undifferentiated wholes; they contain two distinct parts, traditionally called radicals. The radical on the left is can indicate the meaning, and the radical on the right, the sound. Now the sound radical - sometimes called the phonetic - indicates the sound of the whole character, not some part of it. So it's not like the letter B in BIT, that indicates just the first sound of the word. In Chinese a part stands for the sound of the whole character. So far so simple. There is a tricky bit. Only 36% of sound radicals are a reliable guide to pronunciation - in our terms, consistent. The rest are more or less unreliable. The following figure shows an inconsistent phonetic radical with a congruent and an incongruent pronunciation.

You can see that in the character top left of Figure 6 contains a radical that on its own is pronounced PING, the same way as the whole character. If every character in which this radical occurred was pronounced PING than we say that the radical is consistent. However, this radical is not. The character top right contains it, but is pronounced CHENG. The radical is thus inconsistent, but with a congruent reading for PING and an incongruent reading for CHENG.

This property allows Chinese readers to make regularisation errors - comparable to reading PINT as /pɪnt/. So here we have a kind of analogue of irregular English spellings. Of course, there are no letters. But suppose instead of thinking of letter-sound route, we thought more generally of *an analytic route* - that takes the parts, be they letters or radicals - and a whole word route - one takes the whole word, be it a letter string or one or more characters. We would then be able to use the same model for Chinese as for English, mutatis mutandis.

FIGURE 6: REGULAR AND IRREGULAR CHARACTERS IN CHINESE

Regular character	**Irregular character**
评	秤
Pronunciation: [Píng]	Pronunciation: [Chèng]
Meaning: comment	Meaning: steelyard

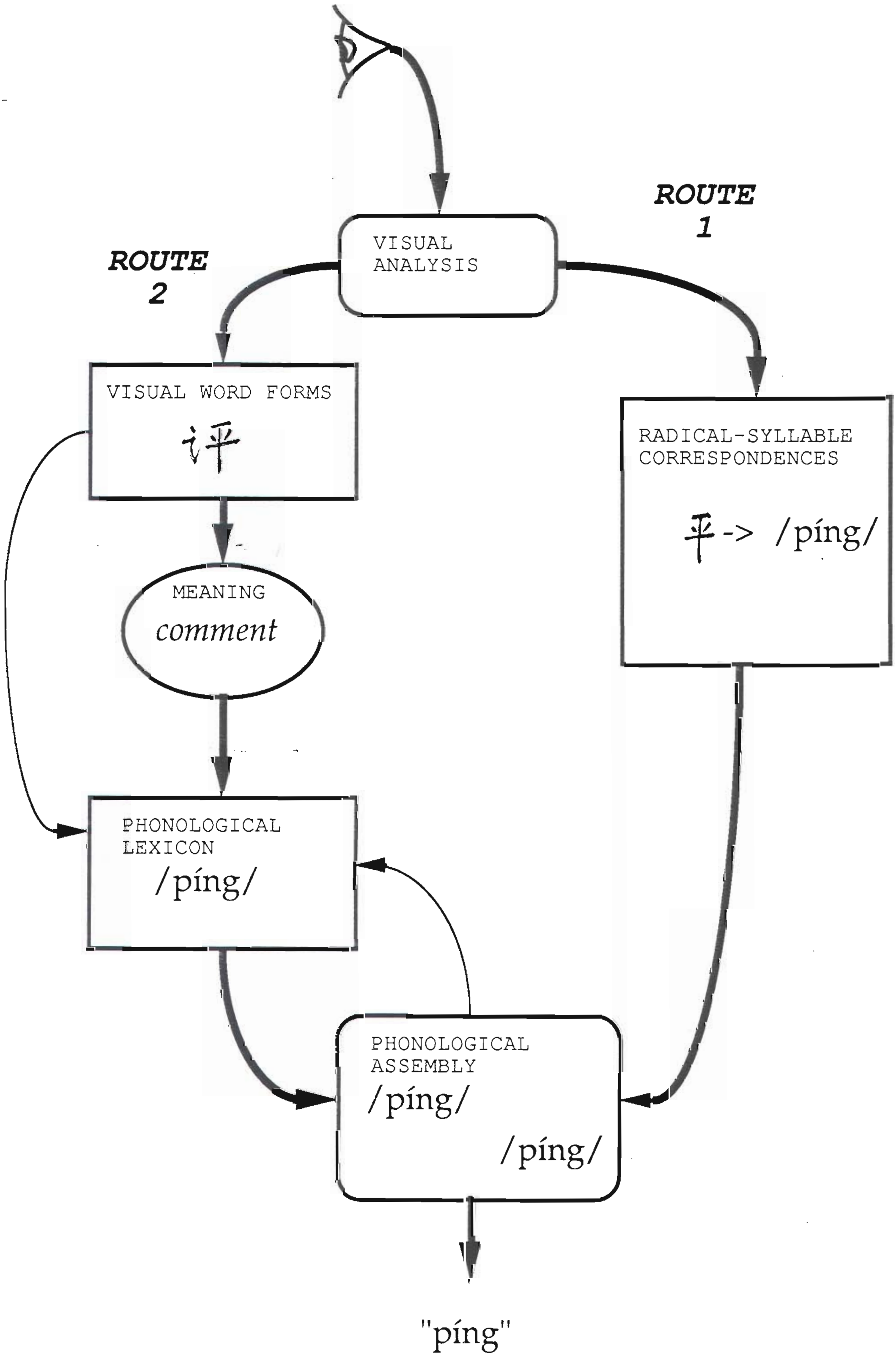
Phonetic radical

平

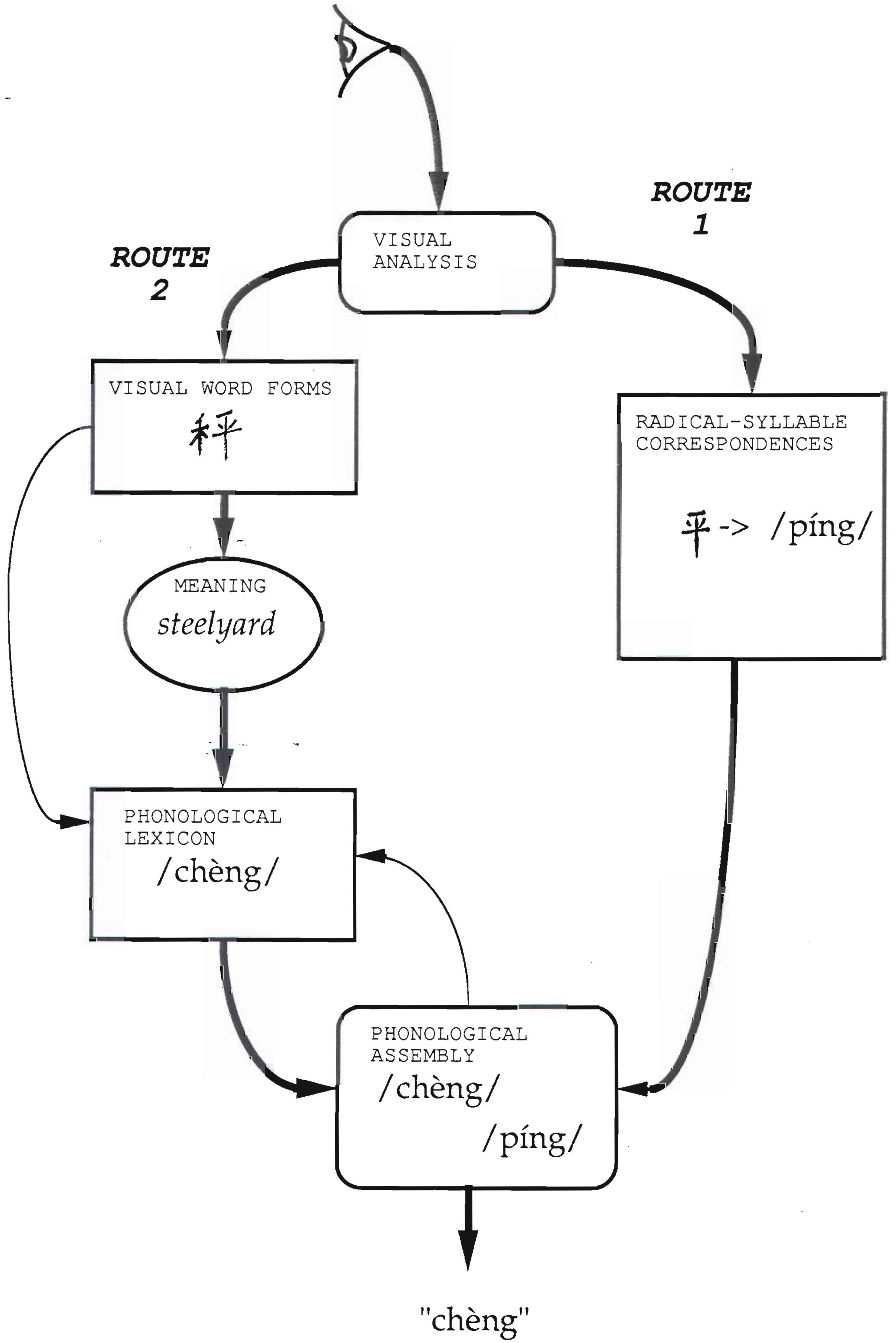
Pronunciation: [Píng]
Meaning: level, flat

REGULARIZATION

秤 [Chèng] ------ pronunciation: [Píng]



ROUTE 1
ROUTE 2
VISUAL ANALYSIS
VISUAL WORD FORMS
评
MEANING
comment
RADICAL-SYLLABLE CORRESPONDENCES
平 -> /píng/
PHONOLOGICAL LEXICON
/píng/
PHONOLOGICAL ASSEMBLY
/píng/
/píng/
"píng"


ROUTE 1
ROUTE 2
VISUAL ANALYSIS
VISUAL WORD FORMS
秤
RADICAL-SYLLABLE CORRESPONDENCES
平 -> /píng/
MEANING
steelyard
PHONOLOGICAL LEXICON
/chèng/
PHONOLOGICAL ASSEMBLY
/chèng/
/píng/
"chèng"

Now is this just procrustean, or is there a neural basis to it? We studied 11 neurological patients with reading disorders. They are listed in Table 7

Patients	Writing	Listening	Speaking	Hemisphere	Location
QXS	+	-	-	left	MCA area
LWY	-	+	+	left	temporal occipital
LYM	+	+	+	left	temporal
LSH	- -	-	+	left	parietal temporal occipital
LQF	- -	+	+ -	left	BG* area CR* area
LZY	+ -	+	+	left	parietal temporal occipital
WBY	+	-	-	left	parietal temporal occipital
LSJ	-	- -	+	left	parietal temporal occipital
LLH	-	-	-	left	frontal temporal
LDJ	-	+	- -	left	parietal occipital
ZZG	- -	+	-	right	frontal parietal

BG: basal ganglia. CR: corona radiata.

The symbol '+' means normal; '+ -' means slightly impaired; '-' means impaired; '- -' means severely impaired.

TABLE 7: CHINESE PATIENTS
(from Butterworth & Yin, 1991)

Now recall two key predictions from deficits to the two routes: if the analytic route (Route 2) is damaged then you will get semantic errors in reading; while if the whole word route (Route 1) is impaired, then we should find regularisation errors.

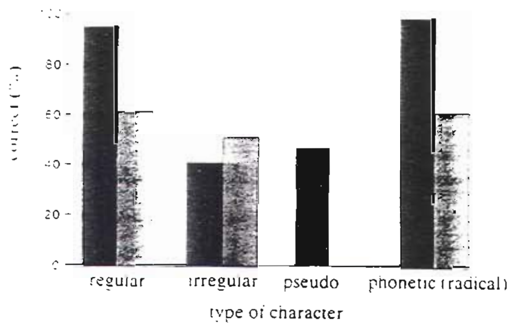
types	patients	semantic errors[a]	regularizations[a]
deep dyslexia	Q. X. S.	24	0
	L. Y. M.	45	0
	L. L. H.	54	0
	Z. Z. G.	57	0
	L. D. J.	50	0
	L. W. Y.	47	0
	L. S. J.	41	0
surface dyslexia	L. S. H.	17	46
	L. Z. Y.	21	53
	L. Q. F.	14	25
	W. B. Y.	0	75

[a] Percentage of total errors.

TABLE 8 REGULARISATION AND SEMANTIC ERRORS IN 11 CHINESE PATIENTS (from Butterworth & Yin, 1991)

As we can see from Table 8, the 4 patients at the bottom made regularisation errors, just like the English surface dyslexics, but the first 7 in the table did not make regularisation errors. But they did, however, make far more semantic errors. English patients do not make both kinds, and it is subject of our current research to discover why this difference should be. We therefore classified patients who made regularisation errors as "surface"dyslexics and those who did not as "deep" dyslexics. As you will see below, the distinction made on the basis of this simple criterion turned out to be exceptionally fruitful.

The other key predictions concerns how the two types deal with different kinds of words. Only those with an intact analytic route will be able to read new words, or what in our Chinese experiments we call pseudo words, but at the same time these readers will be much better at reading words that are regular. Those relying exclusively on the whole word route, should be equally good (or bad) on regular and irregular words, but unable to read new words. And this is just what we see in Figure 9.



Single word reading. Black bars, surface dyslexia: striped bars, deep dyslexia.

FIGURE 9 : READING ALOUD REGULAR WORDS, IRREGULAR WORDS, RADICALS AND PSEUDOWORDS BY CHINESE DEEP AND SURFACE DYSLEXICS
(from Butterworth & Yin, 1991)

So it looks as though the same two components - analytic and whole word processes - characterise Chinese and English readers, each with independent neural substrates, since each can be separately damaged. If that is correct, then the organisation of reading processes in the brain may be determined in their overall architecture not by the social practices the reader acquired, but by some preference the brain has for organising at least some kinds of perceptual work into parallel streams, one global and one analytic.

We have recently gone some way to establishing the anatomical basis of this distinction. With the help of Dr Peter Rudge, a neurologist at the National Hospital for Neurology and Neurosurgery in London, we have been mapping the lesions from our clearest cases of reading disorder. We have seen two Chinese pure alexics: that is, patients with severely impaired reading, but with intact writing or other language skills. These patients show the classical locus in the left occipital lobe described by Déjerine in 1892. Our theoretically ambitious distinction between deep and surface dyslexia turns out to correspond to a very clear anatomical distinction. The three surface dyslexics for whom we have adequate scans all show small areas of damage in near the angular gyrus. Now this is where we would expect it to be. The angular gyrus is thought to be an association linking visual and language functions - it lies between the visual areas in the occipital lobes and Wernicke's area. So potentially a good place to locate the visual forms of words.

The deep dyslexics have much larger lesions, as has been noted for English language deep dyslexics (Marin,1980) than surface dyslexics (Vanier & Caplan, 1985). For our three patients, the common area of damage lies frontally from Wernicke's area on the superior temporal gyrus. (I hope to have decent pictures by the time of the meeting.)

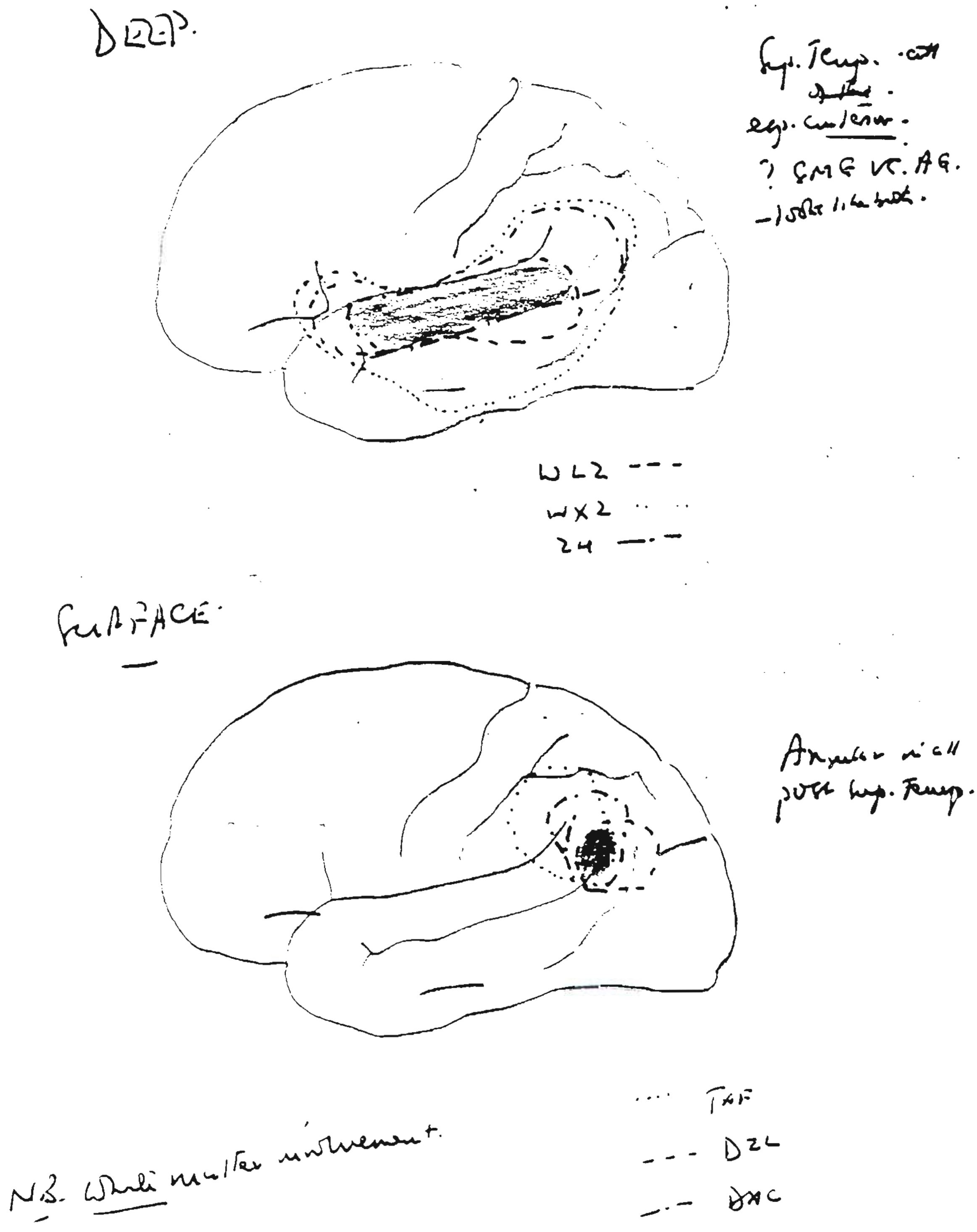


FIGURE 10: THE ANATOMICAL CORRELATES OF DEEP AND SURFACE DYSLEXIA IN CHINESE

In Figure 10, there is no region of overlap between the common areas of deep and surface dyslexia. This is, as far as I know, the best currently available anatomical support for our two routes.

Now the two route idea is a claim about the *acquisition* of reading skills. Frith (1985) has shown that children (perhaps I should say English children) learn to read in distinct stages, one of which focusses on words as wholes and another on letter-sound rules. If the brain likes to set up these separate routes, then it is possible that some innate condition will inhibit the development of one or other - with predictable consequences.

Now the child with an inherited impairment of the neural basis of the analytic route will, on this model, have trouble reading new words, but will be able to learn words by rote; while the child with an impairment of the global route will have trouble with irregular words (if he or she is unfortunate enough to be reared in a culture with irrational spelling practices - like Britain's or China's).

As it turns out, Ruth Campbell and I studied a girl, RE, who appeared to have the former condition. She could read and define words that were very uncommon and irregularly spelled, but had the greatest with even the simplest nonwords.

R.E.

21 years old, 3 A-levels, degree in Psychology.

can read:
PHLEGM, PUERPERAL, CATACOMB, SUBTLE, IDYLL

can't read:
OWN, OWT, NOO, HOZ

(adapted from Campbell & Butterworth, 1985)

J.A.S.

22 years old, 3 A-levels, degree in Psychology.

can't read:
INDICTMENT, CHAOS, POSTHUMOUS, KINETIC

can read:
MUNT, SEAD, OBTEMP, PLAZJUT

(adapted from Goulandris & Snowling, **)

TABLE 9

The complementary condition was reported recently by Goulandris and Snowling. JAS appeared to have an inherited impairment of the global route. She was showed striking regularization errors: like /ɪn'dɪktmənt, 'tʃei əs/, /pəust/humous, /'kɪnetic/. On the other hand, she had no problem reading new letter strings. even complicated ones like PLAZJUT.

In evolutionary time, reading is a recent development of homo sapiens, and only very recently indeed has it become a skill that would be relevant to the reproductive success of a large proportion of the population. Therefore, one might have thought that reading would be an ideal candidate for social practice to shape the organisation of the brain. Surprisingly, perhaps, this does not seem to be the case. Rather, the broad neural architecture of reading, at least of the two very different writing systems I have examined, seems to be shaped by the brain's preference for organising perceptual processes into analytic and holistic streams.

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