The Evolution of Dual Route Model and Its Capacity for Pedagogical Implication

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Abstract
Among the world’s writing systems, the Chinese logographic system is considered to contrast markedly with alphabetic systems such as that used for English. Due to the very different grapheme-phoneme correspondences (GPC) in these writing systems, word reading has often been supposed to differ radically for English and Chinese readers. Original Dual Route model predicts one group resorting to sound but the other relying on visual graphic cues to achieve word recognition and comprehension. This is the essence of the original Dual Route word reading processing. However, recent studies have offered an alternative perspective on this, exploring a variety of factors in readers’ cognitive processing, and finding that phonological processing is universally available to all readers regardless of their writing system background, of which saying even applies to readers with Chinese as L1 (reader’s first language or mother tongue) who can then, in fact, learn English as L2 (reader’s second language) more successfully as a result of it. Here we would like to review the evolution of Dual Route Model and its related experiments, first cross-linguistically and then specifically for Chinese word reading, followed by Parallel-Distributed (or Interactive) Processing Model as a contrast. The purpose is to establish background information on the available models which attempt to explain the process of word reading/recognition, as well as cognitive factors which might also affect readers’ use of the available phonological and orthographic processing routes. The end goal is to depict how the development of the dual mechanism evolves to embrace the interactive components of word reading processing, thus provides pedagogical value which is universal in specifying readers’ cognitive effects on how readers process their L1 and L2 word reading.

Key words: Dual-Route model, Parallel-Distributed (or Interactive) Processing Model, grapheme-phoneme correspondence, phonological processing, orthographic processing.
1. Introduction

The relationship among writing systems, orthographies, and languages has been described in Perfetti (1997, p23):

“Languages provide multilevel units in phonology (phonemes, syllables, onsets, rimes...) and morphology. Writing system principles select one or more levels of language for encoding into elementary writing units. Orthography is the system of constraints on the writing units including their mapping to language units.”

Starting from this perspective, a common assumption has been that the process of comprehending written language is linked to different types of orthographic structure; languages’ different script-speech relationships are held to lead to different types of word processing (Tzeng & Hung 1981). These differences in processing are held to arise from whether, and if so, in what way, a word’s graphemic representation is related to its phonological representation, a link that crucially relies on the existence of GPC rules (Venezky 1995). For example, Hebrew is an orthography where all diacritics are omitted in its written form; therefore, unless it is read in the context of a sentence or passage, readers can in no way identify the meaning of a word nor pronounce the vowel of the word as this is specified by the diacritics. Thus, the writing system does not support a full set of GPC rules and is considered a ‘deep’ orthography in terms of the Orthographic depth hypothesis (ODH) due to the opacity of its letter-to-phoneme correspondences. This concept of GPC based orthographic depth is well described in the following statement by Katz and Frost (1992, p71):

“An orthography in which the letters are isomorphic to phonemes in the spoken word (completely and consistently) is orthographically shallow. An orthography in which the letter-phoneme relation is substantially equivocal is said to be deep (e.g., some letters have more than one sound and some phonemes can be written in more than one way or are not represented in the orthography). Shallow orthographies are characteristic of languages in which morphemic relatives have consistent pronunciations.”

In relation to our focal languages, Chinese and English, in which spoken words are represented by radically different systems of written symbols, the former is phonologically opaque when compared to the latter. Thus, one key account of the process of word reading in Chinese and English is provided by the ODH. Chinese is ‘deep’ when compared to English, and graphic-phonological correspondences (GPCs), more readily formulative for English than for Chinese. The ODH predicts that a shallow orthography such as English will encourage readers to read words mainly by involving the language phonology, while a deep orthography such as Chinese prompts readers to resort
to strategies mediated by the printed word’s visual orthographic structure. Comparable to ODH hypotheses, there are two current psycholinguistic models, Dual Route Model and Parallel-Distributed (or Interactive) Model, endeavoring to explore the similar issue based on the simulation of their operation mechanisms: before we proceed to further discussion on how word reading was illustrated in these two models, it is crucial for us to briefly contrast the nature of Chinese and English writing systems.

1.1. A comparison of Chinese and English writing

Chinese writing system has followed a progression from the early semasiography to logographs where each symbol corresponds to a single particular morpheme and where orthography is a mapping of written symbols directly into meaning, while at a certain stage that rebus system was introduced to represent the spoken language, e.g. like 青 (qīng) which has the symbol for green used just to indicate the sound, which is exactly the rebus principle; for English, and other alphabetic systems, the progression has been from a rebus system, the representation of a word or phrase by pictures that suggest how it is said in the spoken language, to a syllabary, and then to an alphabet. The concept behind this type of orthography is “sound writing” (Tzeng & Hung 1981). Comparatively speaking, the Chinese writing system as a logographic system primarily represents the meaning of a word or morpheme and secondarily its sound. English, an alphabetic system, represents primarily sound units where one letter represents one phoneme (Taylor & Olson 1995, DeFrancis 1984). This difference has been recognized and classified in a linguistically grounded dichotomy referring to logographic Chinese as ‘pleremic’, semantically informed by the graphemes of the script, and to alphabetic English as ‘cenemic’ since its graphemes are; in contrast, semantically empty (Henderson 1982). This feature enables the Chinese writing system as a morphemic script to be as linguistically productive as an alphabetic orthography and is reflected in the pervasive nature of heterographic homophony. This is limited in English in two respects. First, homophones are not particularly common, as can be ascertained by consulting a standard dictionary. Second, a particular set of homophones typically has only a small number of members, e.g. lead, led (2), rough, ruff (2), etc… The variation in spelling obvious serves a morphemic purpose to distinguish homophones. By contrast, Chinese has very many homophones and a typical set of homophones has many members. For instance, in Chinese the number can be comparatively high as in the example of the syllable /xī/, which can be ‘west’ 西, ‘breathe’ 吸, ‘river’ 溪, ‘hope’ 希, etc. (Chao 1968a). This set of homophones can add up to at least 30 characters in a contemporary Chinese dictionary. This morpheme based feature, in contrast to the writing system used in English, can also be seen in the phenomenon that despite the number of Chinese languages and dialects, a uniform written language can be used for communication and be understood by Chinese people even though their spoken forms are mutually unintelligible. This cannot be achieved in an alphabetic or a syllabic writing system where pronunciation is constrained by grapheme-phoneme conversion rules and ‘written versions of the
dialec
ts would be correspondingly mutually incomprehensible to one another’ (Hoosain 1995).

A further way of describing the difference between Chinese and English orthography refers to the notion of grapheme-phoneme correspondences (GPCs) which are linked to the idea that orthographies vary along a continuum of phonemic transparency and opaqueness (Leong 1995). If GPCs are regular and easy to state as simple rules, orthography is regarded as shallow. By contrast, for deep orthographies, GPCs are complex or even impossible to state. Italian is an example of a language where the grapheme-phoneme correspondences are transparent and which is correspondingly viewed as having a shallow orthography. In contrast, Chinese has a phonologically opaque writing system which can be categorized as deep. English has a shallow writing system compared to Chinese, but because of many irregularities, it is deeper then Italian. These irregularities can be seen for the letter sequence -ough in Table (1):

Table 1. English words contain the letter sequence -ough

<table>
<thead>
<tr>
<th>Spelling</th>
<th>Pronunciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. bough</td>
<td>/bɒu/</td>
</tr>
<tr>
<td>2. cough</td>
<td>/kɔuf/</td>
</tr>
<tr>
<td>3. dough</td>
<td>/dɔu/</td>
</tr>
<tr>
<td>4. rough</td>
<td>/ˈraʊf/</td>
</tr>
</tbody>
</table>

In relatively shallow systems, the primary function of phonological units is to establish a phonological representation, rather than to provide semantic information (Mori 1998). In contrast to this, Chinese orthography does not directly map to individual phonological segments and is morpheme based (Tzeng & Hung 1981), for the most part, with every character representing a single morpheme and corresponding to a single syllable at the phonological level (Norman 1993). As already noted, syllable structure in Chinese is rather simple, there being no clusters of consonants before and after the nuclear vowel (Wang 1973). When loan words with consonant clusters appear in Chinese, they are broken into CV syllable structure units. For example, Prof. ‘Atkinson’ will be rendered in Chinese writing as four syllables, 艾(ài) 特(tè) 金(jīn) 森(sēn) in four characters. The Chinese language uses about only 400 distinct segmental syllables, a number that grows to about 1,300 when tones are taken account of. By contrast, English can rely on over 5000 (C)V(C) syllables, a number that grows considerably when consonant clusters are taken into account. In the next chapter we will take up the matter of how words are actually processed psychologically when read.
2. Models of Word Reading

2.1 The evolution of Dual Route Model (DRM) and related studies

One popular model has involved the postulation of two routes in word reading and this dual route model (DRM) has been used to explain the results of word reading experiments (Foster 1994, Hoosain 1991). The two routes resemble the two types of independent processing suggested by the ODH.

An early idea of how the mental lexicon is searched for words is the Search Model. This considers lexical access to occur after a serial scan of words until a match is found between the incoming sensory information and a lexical entry (Taft 1991). In view of the inefficiency of a search which requires complete access to lists of known words, it is suggested that word search occurs via subsets of lexical entries or ‘bins’, which are organized on the basis of sensory characteristics such as the initial and final letter of the word. Once these characteristics are identified, the word recognition process will then search either for a compatible orthographic access file, or for a phonological information access file, the auditory form of the word. Either of these leads to the corresponding master file where the relevant word information is stored (Foster 1994). Thus, it is assumed that word reading potentially involves the computation of three types of representation: orthographic, phonological and semantic. To access the semantic representation, phonological and graphic (sometimes called visual) information is used by the two major word recognition routes in the general framework of the DRM. The two types of processing arise from differences in the role of GPCs in regular and irregular words. The former can have their letters processed and converted to sounds by GPC rules to access the meaning; the latter allow only a visual graphic route, since they do not engage GPCs and the meaning of words must be directly accessed from visual lexical information (Henderson 1982).

The two different routes in DRMs are also identified as non-lexical and lexical routes with the former often called a GPC or phonological access route where GPCs have been learnt; the latter is called a visual access route, where no direct correspondence between grapheme and phoneme exists, and therefore, direct access to meaning is necessary. It is important to be clear that a DRM typically sees both routes as used even within one language such as English, with irregularly spelt words being identified via direct orthographic processing and regular words via GPC based phonological processing, sometimes, referred to as involving ‘assembled phonology’ (Morton & Patterson 1980, Coltheart & Rastle 1994). Thus, reading of irregularly spelt words such as yacht can bypass the phonology, while reading of others such as fun engages phoneme constituents via GPCs.

In Coltheart (1980), the existence of a non-lexical route (a route relying on phonological codes) is further differentiated from a lexical route (a route using a visual graphic code) and is investigated in experiments in terms of the availability of phonological information processing. The non-lexical route
enables subjects to read a pseudo-homophone such as ‘phocks’ in a sentence requiring a semantic decision task like “Does ‘phocks’ sound like a kind of animal?” If the subject responds yes, it indicates access to a phonological route; if the subject rejects such a sentence, it indicates access to a lexical route, or visual graphic route, which enables subjects to reject ‘phocks’ as a kind of animal since ‘phocks’ is visually and graphically dissimilar to ‘fox’. This visual graphic route also applies to exceptional words, such as ‘aisle’ where ‘s’ is not pronounced. It offers a way of processing words when no GPC rule can be followed.

A DRM proposes that if the script of a language primarily represents the sounds of the language, readers are more likely to get to the meaning via phonological recoding. However, a direct script-meaning relation may be applicable to reading languages with deep orthographies where the word reading process will resort to the visual graphic route to achieve meaningful comprehension (Forster et al. 1987, Hoosain 1991). An example of the former is provided by English where spelling is partially regular and phonological representations can be generated directly from written letters: hence, English is mainly read through this phonological route. An example of the latter is Chinese, where characters exhibit no reliable GPCs and so phonology is derived from the internal lexicon, with reading mainly achieved through the graphic visual route, just as for the irregularly spelled words in English.

We have observed earlier that if a word is regular with respect to spelling, then the reader is expected to go down the phonological route, while irregularly spelt words will prompt readers to resort to the graphic visual route. However, a further feature of DRMs is that the degree of familiarity with a lexical item also plays a role in the selection of the route used for word reading. The claim is that words that are very familiar to a reader, even when regularly spelled, will be read using a direct visual graphic process, a similar point which was indicated in the result of Seidenberg’s study (1985). Alternatively, it is maintained that the indirect, non-lexical route, involving GPCs, applies to new words where phonological representations become a necessity as such forms have been not yet previously encountered nor stored in the lexicon. Both of the above conditions are also very much related to readers’ word reading and learning experience. In general, then, it has been supposed that written word comprehension proceeds via the assembled route when it addresses new and unfamiliar words, while the direct route is applied to known frequent words.

From a different perspective, it might be maintained that a crucial omission from the early DRMs is their lack of a developmental component involved in word reading. Specifically, early DRMs do not take account of readers’ cognitive development in relation to the word processing which can be potentially affected by learning experiences. A DRM might suppose that a beginning reader uses one or other route, depending on the characteristics of the orthography to which they are exposed. But if advanced readers typically have both routes available, it is necessary to say something about how this development takes place. As Barron (1986, p104) puts it:
“DRM lacks adequate characterization of the knowledge or the processes that children employ in attempting to read words during the transition period between being a non-reader and being a reader.”

One way of thinking about this problem is to suppose that both routes are available and accessed from the onset, and this proposal is adopted by a particular type of DRM known as the Horse Racing Model.

Like other types of DRM, the Horse Racing Model recognizes two routes to word comprehension and maintains that the non-lexical phonological route is accessed for lower frequency, unfamiliar words and non-words, whereas the lexical route relies on graphic visual processing and is particularly suitable for high frequency familiar words. However, it is distinguished from what has been described above in that one route does not exclude the other. In the Horse Racing Model, both routes are accessed simultaneously and a race takes place to see which arrives at the semantic code first (Papp et al. 1992). The independence of the two routes in the model has given rise to difficulties, however, since it has been found that a typical error on an exceptional word sometimes indicates that the processing route was inappropriate. For instance, subjects over-regularized their word reading, such as that gauge /geɪdʒ/ was read as gorge /ɡɔːdʒ/, where gauge was expected to be processed via the lexical route as an exceptional word.

To summarize this brief discussion, we see how phonological and visual graphic information is processed independently in DRMs in a way which is primarily due to orthographic properties, but also to some extent, to the frequency of words. However, some weaknesses in DRMs, including the Horse Racing Model, have been mentioned, and we conclude this discussion by introducing the dual-route cascade (DRC), a version of a DRM that seeks to overcome these, that illustrates a fully interactional system with bi-directional connections within each route, together with a shared system that channels these routes for access lexicon information and a point for these routes to come together (Coltheart and Rastle 1994).

Different from the previous version of DRMs, DRC was developed into a model with a comprehensively interactive as well as serial word processing capacity: a GPC based route and lexical processing route. The latter was subdivided into a nonsemantic route and a lexical semantic route. In DRC, the two routes share the same initial stage: first a visual feature detector processes the printed word and second letter detectors serve to identify letters. This leads to two different routes as described, which come together through the phoneme system to generate the output. Distinct from previous DRMs, DRC involves the activation of processing in various components rather than as an all-or-none event, that is, visual word recognition and subsequent reading aloud is achieved after numerous processing cycles rather than being activated as soon as the
Cascaded processing regards processing as being activated between different levels, in contrast to previous DRMs where one level of processing has to be completed before another can be activated. According to this sort of model, a lexical process is fully interactive and parallel, while a non-lexical process maintains its serial but bi-directional nature. The former route can read high frequency words or familiar words that are already stored in the lexicon, while the latter applies to unfamiliar words that have not yet been learnt. In this model, a fully interactive processing system was introduced with a shared initial and final stage for both routes and a sketch of its architecture appears in Figure 1.

Figure 1 The overall architecture of the DRC based on Coltheart et al. (1986) and Stuart (2002):
An example that might impressionistically approximate how the system is supposed to work can be illustrated in the following example. Taking a child learning to read the word *goat*, DRC would prescribe word processing to start with the visual feature detectors leading to the letters g-o-a-t being activated. Meanwhile, the phonological representation of the word *goat* will be activated as a phoneme unit /g/-/o/-/t/, so the child will be able to name the word correctly via GPC when the semantics of the word ‘*goat*’ are also activated simultaneously by, say, a picture. Here we see that the semantics is activated by the lexical route in accordance with nonlexical processing. The letter units that are familiar to the child and the corresponding phoneme units will also be activated.

However, in DRC, it is acknowledged that beginners often learn about consonants such as ‘g’ /g/ and ‘t’ /t/ prior to vowels such as the digraph ‘oa’ /o/, as consonants frequently appear at word boundaries. The lexical as well as nonlexical processings will keep feeding back to the letter detectors so any word being learnt will be stored with familiar words with the initial letter ‘g’ and final ‘t’, until ‘oa’ /o/ is matched leading to a whole orthographic representation in the lexicon. Here we see that DRC gives an account of an example of sight word reading being learnt via the lexical as well as the nonlexical route: both the peripheral letters and phonological representation are facilitated via the GPC route resulting in a proper orthographic representation, which will also be stored in the lexicon as a familiar word for future reference. Thus, we see that the DRC successfully deals with word reading and learning experience and is ‘sufficient interactive with both lexical and nonlexical feedback systems and shared components across the two systems, to extend its usefulness from merely providing an insight into what must be developed to providing also an explanation of how this development might come about’ (Stuart 2002, p59). Here we observe how the potential cognitive factors such as learning and development variants can be applied within the DRC and facilitated via two routes that are available to the readers.

Setting aside details of different DRM’s, a comparison of the English, language with a relatively shallow orthography, and Chinese which has a deep orthography, yields the natural prediction that one route, the direct visual graphic route, will be available to readers of the latter. It is as if every word is irregularly spelt in Chinese and orthographic processing provides the meaning of a word by direct association with its visual, graphic form. Phonology will be engaged or activated, according to this conception, as “addressed phonology” only after the word has been identified, i.e. we will find only post lexical phonological processing.

To sum up, orthographic processing is characterized as a “direct meaning” based route, where meaning is directly accessed via visual graphic cues, while phonology is assembled via the recognition of the word’s visual form without prior retrieval of meaning during phonological processing (Humphreys et al. 1982). With these two distinct routes available to readers, here we would like to establish a place for learning effects. Supposing someone has been exposed to
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English all his/her life, largely relying on the phonological processing route, but, on various occasions, he/she has also resorted to the orthographic processing route. Plausibly, the phonological processing route, being more practiced due to the nature of the writing system, is more readily available to such a person than is the orthographic processing route. By contrast, another exposed to Chinese all his/her life, relies largely on orthographic processing, then the lexicon route is more practiced and facilitated.

If they now both meet a new script, we will expect the first person to rely on phonological processing and the second to do the same thing with orthographic processing. Depending on the nature of the new script, we would expect to find differences in reading behaviour. An oversimple statement by Fang et al. (1981, p.616) when readers’ learning experiences come into the picture:

“a reader of alphabetic writing cannot refrain from applying an abstract rule system (GPC) to the word, whereas a reader of Chinese cannot refrain from configurational (visual graphic) processing of the logograph.”

The remark has no place for learners’ cognitive development. However, the latest DRM, DRC, architecture obviously has space for such an effect to exist. We now turn to consider some experimental studies investigating DRMs.

2.1.1. DRM studies on word reading

It was assumed at one time that Chinese readers rely exclusively on the direct visual access route when reading words because their writing system is devoid of GPCs (Baron & Strawson 1976). Hence, pedagogically, memorization of pronunciations via repetitive reciting has become a prevalent teaching methodology for beginners (Liu et al. 1983). However, deficiencies were addressed even in the context of the English writing system on such a method: firstly, there is a problem to handle the increasing number of new words; secondly, it is a demanding task for instructors to teach individual newly encountered words since no principles are taught for readers to follow when confronted with new words.

Opponents of this view however, believe that phonological awareness can be relevant in Chinese word reading even though the writing system itself lacks orthographic-phonological correspondences. It is crucial for our studies to review and discuss experiments related to DRMs, in order to examine the potential learning and development experience that is compatible within the framework of DRM.

2.1.2. Studies using Stroop tasks

One experimental technique that has been widely used in assessing the plausibility of the proposition that readers have access to two distinct processing routes is the Stroop Test. Early relevant studies focused on Stroop colour tachiscoscope tasks performed by bilingual subjects using alphabetically written
languages in order to investigate how orthographic differences affect word reading. Two independent word processing routes were assumed, a phonological route, and visual graphic route. The phonological representation is considered to be directly associated with only the operation of GPCs but concrete perceptual information such as pictures also are associated with visual graphic processing. This perspective might be applied to the case of the Chinese writing system since the Chinese readers are presumed to use the same visual channel to recognize characters as they do to recognize colours.

In a monolingual Stroop test, the subject is required to name the colour of a stimulus, which might be (a) a coloured patch or a set of Xs, which acts as a control; (b) a colour word distinct from the colour in which it is printed, e.g. *green* is presented in red. RTs are measured, and the typical finding is that subjects take longer to respond under (b) than they do under (a). The difference between reaction times (RTs) to (b) and to (a) measures the size of the *Stroop effect*. Bilingual versions of the test, introduce additional conditions. Specifically, alongside the situation where the subject is presented with a colour word in one language and has to name the colour of the stimulus in that language, it is also possible to ask a bilingual subject to respond in their other language. For instance, a bilingual subject with English and French can be presented with *green* in red, and the required response is *rouge*. Thus, in bilingual Stroop tests, we have both intralanguage conditions, corresponding to the monolingual case, and interlanguage conditions.

Let’s now consider monolingual Stroop tests for English and Chinese. Is there any reason to suppose that Stroop effects will be different for the two languages? In both cases, we would expect there to be interference because of the incompatibility between the colour’s name and the colour in which it is printed. However, if we suppose that the recognition of Chinese characters relies largely on a visual process and does not systematically engage phonology, we might expect that the interference will be larger in the case of Chinese than for English, *i.e.* Chinese readers will exhibit bigger Stroop effects than English readers.

A Stroop test was used by Biederman and Tsao (1979) to compare the process of word reading in English and Chinese by two groups of subjects. An English-speaking group included 5 undergraduates and 11 graduate students, and a Chinese group contained 16 native Chinese from Taiwan, 7 of whom were undergraduates and 9 graduates and all were, to varying degrees, bilingual in English. Four tasks were given to each subject requiring use of their native language throughout:
Table 2 A modified Stroop test used by Biederman and Tsao (1979)

<table>
<thead>
<tr>
<th>Type</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Colour naming of patches</td>
</tr>
<tr>
<td>b</td>
<td>Colour naming of colour words or characters for colours, which are incompatible with the physical colours used in the stimuli. Subjects were asked to focus on naming the colour and to ignore the letters or characters.</td>
</tr>
<tr>
<td>c</td>
<td>Reading coloured words. Subjects were asked to focus on reading the words and characters and to ignore the colour.</td>
</tr>
<tr>
<td>d</td>
<td>Reading black letters or characters.</td>
</tr>
</tbody>
</table>

The colours used were red, yellow, blue, green, and purple. In (2b), the colour of the print never corresponded to the colour named. The order of administration of the tasks was balanced in a Latin Square.

The results showed that the Chinese group displayed more interference than the English group when trying to name the colour of characters/words for incompatible colour words. The mean interference value, print RT minus patch RT was 597 msec for the Chinese subjects and 401 msec for the English group with a slightly higher error rate (ER) of 5.3% (compared to 3.8%), by the Chinese subjects. The authors consider a variety of factors, other than orthography, that might have contributed to their results. One of these is the fact that the Chinese subjects were all bilingual in English to some extent. However, Biederman and Tsao recalculate the size of Stroop effects from previous studies employing bilingual subjects and show that these effects are in fact smaller than those obtained from monolingual subjects. For instance, Spanish-English bilinguals produced a Stroop effect of only 327 msec when presented with Spanish materials. The authors suggest that this reduction is largely due to an increase in RTs in control conditions and they speculate that this increase may be due to competition from the two response languages, which can be a task effect. Irrespective of whether this is correct, the reported figures on the size of the Chinese effect are more than could be attributed just to the factor of bilingualism. The researchers’ interpretation, then, is that Chinese characters in general permit more direct access to meaning than English words, and they further support this position by citing findings that, for example, 鳳梨 (fōng lí) ‘pineapple’ can be classified as a fruit as rapidly as a picture of a pineapple, a situation that contrasts with English where classification based on pictures is more rapid than when it is based on words. Overall, then, this experiment demonstrates that more Stroop interference occurred in reading logographic than in reading alphabetic scripts. The authors claimed that this supports the dominance of the visual graphic processing route when processing Chinese compared to processing English words.
As noted, a further issue that has been studied using Stroop experiments is that of the differences between intralinguage and interlinguage conditions for bilingual subjects. A three-way series of cross-linguistic Stroop experiments was conducted by Fang & Tzeng (1981) with Chinese-English, Spanish-English and Japanese-English bilinguals so as to investigate the relation between word reading strategies and orthographic type. For example, given a Spanish-English bilingual, we can measure RTs to name colours in six conditions:

Table 3.1 A cross linguistic Stroop test-English/Spanish version used by Fang and Tzeng (1981)

<table>
<thead>
<tr>
<th>Type</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Coloured patches, where the language of response is English (t1)</td>
</tr>
<tr>
<td>B</td>
<td>Incongruent English colour words, where the language of response is English (t2)</td>
</tr>
<tr>
<td>C</td>
<td>Incongruent Spanish colour words, where the language of response is English (t3)</td>
</tr>
<tr>
<td>D</td>
<td>Coloured patches, where the language of response is Spanish (t4)</td>
</tr>
<tr>
<td>E</td>
<td>Incongruent Spanish colour words, where the language of response is Spanish (t5)</td>
</tr>
<tr>
<td>F</td>
<td>Incongruent English colour words, where the language of response is Spanish (t6)</td>
</tr>
</tbody>
</table>

Obviously, in such a situation, we can measure the size of a variety of Stroop effects. Specifically, we can contrast Stroop interference in intralinguage conditions, where the stimulus language and response language are identical, with Stroop interference in interlinguage conditions, where stimulus and response language are distinct. An early finding (Preston & Lambert 1969) was that intralinguage conditions yield more Stroop interference than interlinguage conditions. Thus, in terms of what we have above, t2-t1 is greater than t3-t1 and t5-t4 is greater than t6-t4.

The above finding can be put down to the idea that in intralinguage conditions, interference arising from orthographic similarity is maximized. After all, in such conditions, the response language and the stimulus language are identical. Suppose, now, that we consider this suggestion in the context of English-Chinese bilinguals. Clearly, here orthographic differences between the two languages are very apparent, and, as we have seen, some have viewed it as plausible to maintain that words in the two languages are processed using quite distinct processing mechanisms. If this is the case, we can infer that Stroop interference should be minimized in an interlinguage Stroop test using English-Chinese bilinguals. As a consequence, the difference between intralinguage and interlinguage Stroop effects for such subjects should be comparatively large.
The above prediction was investigated in two experiments in an important study by Fang & Tzeng (1981). The design of the experiments for both groups was as outlined in Table 3.2. for Experiment 1, which was conducted on 30 Chinese-English bilinguals studying at college level, who are identified as Chinese dominant subjects. Experiment 2 was identical in design (see Table 3.1) and was conducted on 30 Spanish-English bilinguals among whom half were reported to be Spanish dominant while the other half were English dominant ‘by their own estimates’. The Spanish/Chinese-English groups of subjects were given six naming tasks. The prediction was that the difference between the size of Stroop effects in the interlanguage and intralanguage conditions would be greater for the latter group than for the former. This prediction was confirmed, with the authors reporting a 213 msec difference in the predicted direction for the Chinese-English group compared to a 48 msec difference, again in the predicted direction for the Spanish-English group.

Table 3.2 A cross linguistic Stroop test-English/Chinese version used by Fang and Tzeng (1981)

<table>
<thead>
<tr>
<th>Type</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Colour naming of patches in English</td>
</tr>
<tr>
<td>B</td>
<td>Colour naming of incongruous English colour words in English</td>
</tr>
<tr>
<td>C</td>
<td>Colour naming of incongruous Chinese colour words in English</td>
</tr>
<tr>
<td>D</td>
<td>Colour naming of patches in Chinese</td>
</tr>
<tr>
<td>E</td>
<td>Colour naming of incongruous Chinese colour words in Chinese</td>
</tr>
<tr>
<td>F</td>
<td>Colour naming of incongruous English colour words in Chinese</td>
</tr>
</tbody>
</table>

At this stage, then, we would appear to have evidence that is compatible with the suggestion that English and Chinese are read using distinct processing mechanisms, evidence which is itself compatible with the architecture of DRMs. This magnitude of a Stroop effect result also is in line with the outcome of Biederman and Tsao’s (1979) experiment. However, a discrepancy was reported with greater Stroop effects for English colour words in Fang & Tzeng’s results when compared to those of Biederman and Tsao. It was recognized that this may be due to the fact that the English subjects were native speakers in Biederman and Tsao’s study while in Fang and Tzeng’s experiment; they were bilinguals with English as a second language. Obviously, such a failure to keep constant subjects’ language background urges caution in interpreting results.

There are further methodological difficulties with Stroop experiments such as subjects with different degrees of bilingualism in their language learning backgrounds. For instance, Fang & Tzeng (1981) report that their
Spanish-English bilinguals are self estimated as dominant in one or the other language, while Biederman and Tsao’s (1979) subjects are English native speakers. Discrepancies in results are even found with reports of Stroop data on word naming tasks by seemingly similar bilingual groups (Potter & Faulconer 1975, Flores d’Arcais & Schreuder 1987). Taking account of such observations, it can be maintained that researchers in Stroop studies rarely provide adequate reports or evaluations of subjects’ first or second language learning backgrounds.

In the same paper, Fang & Tzeng (1981) turn their attention to Japanese for additional perspectives. Colour words, normally written in kanji, can be written in kana, and this provides the opportunity to (ibid) ‘vary the orthographic structures while holding the phonological factor constant (p613).’

In the third experiment, Fan & Tzeng used two groups of Japanese-English bilinguals. Each group took part in an experiment with the features illustrated in Table 4. Fifty Japanese-English bilinguals dominant in Japanese were divided into two groups and the stimulus items were in English or kanji for one group and in English or kana for the other; the responses were spoken English or Japanese for both groups. The thinking behind the design was that if orthographic similarity is the major factor affecting the size of differences in Stroop effects between intralanguage and interlanguage conditions, these differences should be larger for the kanji group than for the kana group. This is because kanji is orthographically more distinct from English than is kana. In fact, the relevant reductions were 121 msec for the kanji group and 108 msec for the kana group, a difference that is not significant even though there was more interference in naming for kanji colour words than for kana. While the authors offer a number of reasons for being cautious, they note that (p615) ‘it does not seem that a strong explanation based upon variations in orthography has gained support….’ We see, then, that even within Japanese, there are doubts about the implications of the findings from Stroop tests as it is difficult to infer anything systematic about the amount of interference and its relationship to the degree of similarity between these scripts. Further uncertainty is due to the fact that the results came from two different groups of bilingual subjects.

\(^{(1)}\) As is well known, written Japanese employs two scripts: kanji comprises Chinese characters and is used predominantly for content words; kana is a syllabary and is used for writing grammatical morphemes and foreign loans.
Table 4. Japanese/English version of Stroop test used by Fang and Tzeng (1981)

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>colour naming of squares in English</td>
<td>colour naming of squares in English</td>
</tr>
<tr>
<td>B</td>
<td>colour naming of squares in Japanese</td>
<td>colour naming of squares in Japanese</td>
</tr>
<tr>
<td>C</td>
<td>colour naming of English colour words in English</td>
<td>colour naming of English colour words in English</td>
</tr>
<tr>
<td>D</td>
<td>colour naming of English colour words in Japanese</td>
<td>colour naming of English colour words in Japanese</td>
</tr>
<tr>
<td>E</td>
<td>colour naming of kanji colour words in English</td>
<td>colour naming of kana colour words in English</td>
</tr>
<tr>
<td>F</td>
<td>colour naming of kanji colour words in Japanese</td>
<td>colour naming of kana colour words in Japanese</td>
</tr>
</tbody>
</table>

To such doubts as the above can be added concerns about the use of studies based on kanji and kana word reading to provide a basis for proposals regarding Chinese word reading. Specifically, it has been noted that word reading involves not only orthographic features of the writing system, but also the distinctive grammatical function and the underlying phonological representation of words. The inference from kanji and kana studies to Chinese word reading may be especially inappropriate because of the difference in the usage of grammatical classes in the Japanese writing system and in relation to readers’ language learning background, which are crucial but are generally ignored by experiments into Stroop effects such as that reported above. They may constitute a tertium quid that provides misleading results. According to Flores d’Arcais (1992, p43-44.):

“There are a number of differences between kanji and kana besides the mere orthographic properties, and they concern the grammatical class involved and the age of acquisition. Kana is used to write function words, grammatical formatives, affixes, etc. Nouns, adjectives and content words in general, except foreign loan words, are normally not written in kana but with kanji. Thus, a major difference between kanji and kana consists in the grammatical class for which the two systems are used. Secondly, there is a dramatic difference in the age of acquisition of the two writing systems in the Japanese child. Kana are acquired earlier, usually before the beginning of the formal school program, while kanji are learned gradually and in a fixed sequence which is planned over the whole range of the first eight years of formal school, with a total of some 900 kanji learned by the end of this period, when the child is already 14 years of age. Of course, it
should make an enormous difference in ease of lexical access whether kanji is acquired at 6 or at 12 or 14 years of age.”

The further discussion of the distinction between kanji and kana, and kana into hiragana and katakana, the former used for grammatical morphemes and the latter for loanwords, is described by Steinberg and Yamada (1978-1979, p90):

“The writing system (Japanese) is more complex than indicated... because kanji may have hiragana symbols added to them, as in the case of verbs and adjectives. The root predicate morpheme will be written in kanji and added to it will be the Japanese grammatical ending, but written in hiragana. While kanji and hiragana are mixed to form words, the katakana and hiragana systems are not. Either one or the other is used in writing a word. Thus, the word terebi is typically written all in katakana, rarely in hiragana, but never in a mix of both.”

Since kanji and kana are largely used in complementary distribution for different grammatical units, and are acquired at different ages, it follows that these factors could contaminate Stroop studies where Japanese subjects read the same word in both scripts. Therefore, the difficulties of making inferences to the case of reading Chinese become even more evident, when we observe that Chinese readers use ‘kanji’ from a younger age than Japanese readers and for all grammatical types. Hence, conclusions about processing kanji using Japanese subjects cannot be transferred to the Chinese case without a good deal of caution.

Beyond specific difficulties associated with Japanese studies, there are further methodological difficulties with Stroop experiments such as subjects with different degrees of bilingualism in their language learning backgrounds. For instance, Fang & Tzeng (1981) report that their Spanish-English bilinguals are self estimated as dominant in one or the other language, while Biederman and Tsao’s (1979) subjects are English native speakers. Discrepancies in results are even found with reports of Stroop data on word naming tasks by seemingly similar bilingual groups (Potter & Faulconer 1975, Flores d’Arcais & Schreuder 1987). Taking account of such observations, it can be maintained that researchers in Stroop studies rarely provide adequate reports or evaluations of subjects’ first or second language learning backgrounds.

Finally, it is suspected that the shortcoming in techniques in Stroop tasks adopted also have been found that might weaken their ability to shed light on what we are interested in(2). Therefore, overall it might be suggested that Stroop

(2) For example, stimulus-response compatibility was recognized as a side factor to affect Stroop results since the interference may be due to translation of the concept, the colour, to the response language, or translation of the stimulus language to the response language. Therefore, the magnitude of interference in naming a colour may contribute to the requirement of extra time to associate an abstract concept to its name or to translate the stimulus language to the response language. Though a Stroop task is intended to activate subjects’ word processing via access to word meaning, which competes with the visual processing of the colour of the stimulus, the relative speed of naming the words’ colours in the experiments cannot be purely
type experiments intending to test DRM have generally ignored crucial elements such as task effects that are involved with word reading, factors such as distinct grammatical functions in the language and acquisition age, as well as the instruction they have received which we already discussed in the previous paragraphs. We now turn to other research that has used experimental techniques to investigate the processing occurring in visual word reading and subjects’ decoding strategies in different writing systems.

2.1.3. Studies using lexical coding memory tasks

Chen and Juola (1982), used a word pair judgment task to assess the role of phonemic, graphemic and semantic information during the processing of word reading in Chinese and English. In lexical coding tasks, the word pair stimuli are equivalent and phonological and graphic similarity are manipulated in the lexical coding tasks. Two experiments are reported:

1. Experiment 1 was a visual similarity judgment of word pairs, on a 7 point scale, ranging from visually identical to completely different(3);

2. Experiment 2 asked subjects to decide which of the items in test pairs were graphemically, phonemically or semantically similar to a word in a previously studied list, by pressing a corresponding button. An immediate and a delay test were also carried out in the 2nd experiment to assess the lexical coding in the memory process.

Twenty-five Chinese-speaking graduate and twenty-five English-speaking undergraduate students were involved in the first experiment, while the second involves 23 native Chinese graduate students and 1 undergraduate student and 24 native English undergraduate students. Chinese subjects were reported to be from Taiwan and China.

Three types of Chinese and English core word pair were adopted in the experiments. They are similar in (1) graphic shape, (2) in sound, and (3) in meaning:

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(3) The first experiment intends to further check whether word processing of Chinese and English versions of phonemic and graphic word pair stimulus is equivalent. After the comparability was confirmed in the first experiment, the semantic word pairs were added in the second experiment to test on the recognition processing. The purpose of the design is to investigate the alternative processing strategies required by different orthographies as ODH predicts, also the potential difference involved in the pattern of memory representations.
Table 4. Chinese and English word pairs used in a lexical coding task by (Chen & Juola 1982)

<table>
<thead>
<tr>
<th>CHINESE VERSION</th>
<th>ENGLISH VERSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>島 (doû) island</td>
<td>patio, ratio</td>
</tr>
<tr>
<td>鳥 (niouû) bird</td>
<td></td>
</tr>
<tr>
<td>唑 (xun`) teach</td>
<td>sight, cite</td>
</tr>
<tr>
<td>訓 (xun`) lesson</td>
<td></td>
</tr>
<tr>
<td>訊 (xun`) message</td>
<td></td>
</tr>
<tr>
<td>海 (hai) sea</td>
<td>sea, ocean</td>
</tr>
<tr>
<td>洋 (yián) ocean</td>
<td></td>
</tr>
</tbody>
</table>

Word pairs were presented on a movie screen and subjects were instructed to push the corresponding button (left or right) to indicate their response as detailed in the experiment 2. Subjects were informed that accuracy is more important than speed, but both were recorded. The same test with new items was carried out with the same group of subjects and there was a 24 hour gap in between the immediate and delay test.

Significant effects were found for stimulus type on error proportions as well as reaction time data analysis; as was significant interaction between stimulus type, the Chinese or English version, and decision type, which is graphemic, phonemic or semantic.

The results indicated that visual representation is highly significant in word memory for Chinese characters, but no strong evidence was found to support phonemic representation of English words. The lexical coding and memory formats for Chinese and English words appear to be different, the alphabetic and logographic writing systems activating different processing mechanisms, which results in different visual encoding processes and subsequent memory codes. Logographic characters heavily activate ‘visual’ encoding which indicates subjects’ emphasis on visual codes in memory; while alphabetic words activate a more integrated code of visual, phonological and semantic information.

The result is a significant one since Chinese subjects seem to use graphic cues rather than phonemic ones; while English subjects generally relied on integrated strategies of graphic, phonemic and semantic cues.

2.1.4 Studies investigating speech recoding

Another type of experiment on DRM examines speech recoding during word reading. A common presumption has been that Chinese readers use orthographic processing to recognize words from the written graphic form to meaning directly without resorting to inner speech recoding via phonological processing (Rayner & Pollatsek 1989).
In a study by Treiman and Baron (1981), readers were (Chinese and English) only required to respond orally ‘yes’ or ‘no’ to sentences they read silently. Two types of false sentence (homophones and controls) were randomly interspersed with true sentence. Typical materials are illustrated in Table 5:

**Table 5. Speech coding task used by Treiman et. al (1981)**

<table>
<thead>
<tr>
<th>1 Chinese version</th>
<th>2 English version</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a. homophone sentence</strong></td>
<td><strong>a. homophone sentence</strong></td>
</tr>
<tr>
<td>煤 (mei) ‘coal’ [homophone of 梅 (mei) ‘plum flower’] 是一種植物. ‘Coal is a kind of plant.’</td>
<td>A pair is a fruit.</td>
</tr>
<tr>
<td><strong>b. control sentence</strong></td>
<td><strong>b. control sentence</strong></td>
</tr>
<tr>
<td>鉛 [(qian) ‘lead’] 是一種植物. ‘Lead is a plant’.</td>
<td>A pier is a fruit.</td>
</tr>
</tbody>
</table>

Subjects were asked to respond as quickly as they could with a judgment of whether a sentence made sense or not. Thus, comprehension is involved in this experiment.

A total of twenty-two English-speaking undergraduates and graduates participated in the experiments alongside eleven Chinese subjects, among whom eight were tested in H.K. and the rest were undergraduates tested in the United States. All of the Chinese subjects were Cantonese speakers with English as a second language. Results from the experiment showed that the Chinese readers were significantly less impaired by homophone sentences than the control sentences compared to the English readers, though they did slow down, additionally, for the homophone sentences. Chinese subjects made fewer errors on homophone sentences than on controls; whereas, this was reversed for English. The result indicates that English readers resort more to speech coding, a type of phonological processing, than Chinese readers since English readers took a longer time and made more errors on homophone sentences compared to Chinese readers. It is suggested that the reason why Chinese readers slow down on reading homophone sentences is that their phonological processing is activated post-lexically, though not for accessing meaning. It is maintained; Chinese readers derive the meaning of printed words by orthographic processing, and then derive sound from meaning afterwards.

This interpretation was also favoured by Tzeng et al. (1977) where subjects were found to be slowed in phonemic similarity tasks. An alternative to accessing the meanings of words via the sound is that sound is not needed to access meanings at all, but is needed to maintain some record of what has already been read. The role of speech recoding, then, might be to serve working memory as a general linguistic activity and be compulsory for prolonging word retrieval.
The above results generally indicate that differences in orthography may have some effect on the use of speech recoding in reading. However, this is perhaps principally not for the mediation of the comprehension for the deep orthography, but in support of word recoding since it is speculated that phonemic recoding or processing is available to readers as a general information processing strategy as DRMs suggest.

2.1.5. Conclusion on DRMs

In this section, a number of empirical, experimental studies have been reviewed to depict the evolution process of DRMs. These have all been concerned with establishing the plausibility of the view that there are distinct processes involved in word reading, recognition and memorization and, to that extent, can be seen as compatible with the basic ideas behind DRMs. Of course, these are also compatible to different degrees with what we might predict on the basis of the ODH. However, we have occasionally seen that there is the possibility of cognitive factors, i.e. learning and development variants playing a role in accounting for results that is consistent with DRMs.

We now turn to a brief discussion of a second class of cognitive models of word recognition, those embracing the architecture of parallel distributed processing (PDPs).

2.2. The Parallel-Distributed (or Interactive) Processing Model (PDP)

PDPs comprise connectionist simulations of the readers’ word reading process, mapping representations of the written forms of words to representations of their spoken forms. An important characteristic of PDP networks is that they ‘learn’ and pronounce both regular and irregular words without resort to the implementation of two separate mechanisms, a proposal that is advocated by Seidenberg & McClelland (1989).

Seidenberg and McClelland maintain that two different levels of linguistic knowledge are represented in English orthography, phonology and morphology. This is indicated by the fact that we can find examples e.g. ‘shoe, chef, sure, precious’, words with the same sound represented by different letters, and these irregularities in GPC distributed in different positions of the letter string require knowledge that is based on the grapheme-speech relationship, namely, a morphophonemic one and the knowledge of orthographic redundancy is necessary for a successful beginner in the reading process. A lack of general knowledge of lexical structure reflected in the orthography and its implication for phoneme sequencing often causes difficulty in early word reading, since the realization of syllables in the orthography is not always consistent, as some words are similar in orthography but differ in syllabic structure (Seidenberg & McClelland 1989). Typical examples can be observed in word pairs where similarity is found in orthography but difference in syllabic structure: ‘waive, naïve’, ‘backed, naked’, and ‘dies, diet’. Based on the above observation, the PDP approach regards English written words as displaying information in
relation to the organization of sub-lexical units, that is, morphological structure, not solely GPC regularity, an aspect which DRMs would predict to be derived on the basis of pre-lexical phonology, that is, GPC rules. PDP generally considers access to phonological information as an automatic consequence of word recognition constrained by the time course of the decoding process. Here we would like to explore in detail how cognitive variants are included in PDP mechanism.

The single mechanism organized in a connectionist model is described by Foorman (1995, p397) as “a mechanism that involves encoding the frequency and consistency of correspondences between orthography and phonology. These correspondences are not the symbolic GPC rules of dual-route theory. Rather, they are distributed representations and weighted connections between units.” In PDP, the processing that occurs is activation-synthesis, in which the orthographic forms of all words, whether regular or not, are activated with their corresponding phonological information. Evidence for a gradation in activation in this model can be observed in word regularity effects where regular words will have shorter pronunciation latencies than exception words. In fact, this is more accurately characterized as a consistency effect and can be observed in differences in reaction times for phonological processing. For example, words containing letters with phonological alternatives, e.g. ’ea’ is pronounced /ɛ/ in head but /i/ in bead, considered as exceptional words, take longer to pronounce than otherwise comparable words containing letters with only one phonological possibility, considered as regular words, e.g. /ai/ in bike or hike. Here, the regular words are simply those words that can be read based on connections between individual letters and sounds where there are consistent phonological representations, while exceptional words are words with irregular spelling where such inconsistency required longer reaction time for the word processing. Another example of differing consistency in regular letter-sound correspondences can be observed in the following examples: wave is a regular inconsistent word since -ave is pronounced /eı/ though it can also be pronounced /æ/ in have, on the other hand wade is a regular consistent word, where –ade is consistently pronounced /eı/ as in fade, made and jade.

Instead of the implementation of a GPC route, PDP addresses the issue of orthographic redundancy, which accounts for the familiarity of the distribution of letter patterns in the lexicon, where words are constrained by their morphophonemic information. PDP differentiates the word reading between wave and wade corresponding to their consistency and regularity in the lexicon. This was tested experimentally on pseudowords such as tave, which resembles inconsistent words, compared with consistent pseudowords like taze. The results showed tave took longer time to read than taze (Glushko 1979). This contrast is highlighted in Foorman (1995, p398) “GPC rules are useful – not as rules to be memorized, but rather as characteristics of spelling patterns to be recognized through training.” However, as we had discussed earlier, this
difference had also been accommodated effectively within a recent form of DRM, DRC. (4)

Here we see both models recognize a difference between regular and irregular word processing with the developmental element of a cognitive process in consideration, though the word learning and reading mechanisms are conceptually different.

An example of the development of the weight of connections fundamental to PDPs can be observed in an imagined child’s experience of learning. If a child had learned to read **cat** correctly in the first place, then this initial word reading experience paves the way to learn more new words with similar patterns such as **hat**, **mat** or **bat** that rhyme with **cat**. Learning to read the word **cat** weights connections towards the correct pronunciation of **hat**, **mat** and **bat**: “These particular words form the corpus of spelling patterns whose frequencies and consistencies weight the connections between orthographic, phonological, and semantic codes (Foorman 1995, p397).” Extending such illustration to Chinese word reading, if children have been taught to pronounce and segment **派** in pinyin (**pai**) or (ㄆㄞˋ) in ZhùYīnFūHaò 注音符號 (ZYFH), then this learning experience likewise paves the way for learning new words with similar sound patterns and the same tone, e.g. **慨**’sigh’ (**kai**) (ㄎㄞˋ), **拜**’worship’ (**bai**) (ㄆㄞˋ), **賣**’sell’ (**mai**) (ㄇㄞˋ) with the corresponding orthographic information. As a result, there is no sharp dichotomy between distinct routes depending on whether words follow the rules or not. Instead, all words co-exist within a single system in which representations and processing reflect the relative degree of consistency in the mappings for different words, that is, a computational model that adopts the idea of word processing as cooperative and competitive interactions among the collective corpus of learnt words. The importance of PDP interactive mechanism was further emphasized in the following statements by Rumelhart and McClelland (1986) regarding skillful readers who can recognize the letters of a word as a whole unit where the letter process linking to one another by an intermediating set of association:

“The importance of these intermediating units is that they expand the processing capabilities of the network. In particular, if the letter units were only linked directly to one another, its capacity to learn about complex patterns would be much more limited.”

(4)With regards to a recent form of DRM, DRC, it is prescribed that an irregular word will cause two competing pronunciations to activate: one is a regularized pronunciation compiled by the GPC rule system in the nonlexical route, while the other is the lexicon route. Both are interactive and reciprocal by nature. As a result of the dual mechanisms, a correct pronunciation will be retrieved with a slow RT (reaction time) due to the time required for the irregularities to be resolved via two potential processing routes.
Each of the orthographic, phonological and semantic codes in a PDP network acts as a distributed representation within the processing channels and has an activation value of its own: “A stimulus word activates featural representations corresponding to letter nodes, which in turn activates words in which that letter occurs at the spatial position in question; activated word nodes inhibit other irrelevant word nodes but in turn excite matched letter nodes, resulting in a complex flow of activation through the network flow of information in parallel” (Clahsen 1997,p7). Word processing is initiated with the extraction of visual information from the input and followed by a single interactive process with differentiation in the availability of orthographic and phonological information over time (Seidenberg 1985).

**Figure 3 is from Clahsen (1997) and is intended to represent the architecture of an Interactive Activation model of visual word recognition (McClelland and Rumelhart 1981):**

![Figure 3: General architecture of PDP word processing model](image)

Word processing is activated by connections between units in reciprocal directions at different representational levels with hidden units mediating between the pools of representational units (Seidenberg & McClelland 1989). The function of the hidden units is to mediate top-down word-to-letter feedback to the orthographic level so as to adjust by reinforcing, sustaining the external input, that is, to compute an excitatory or inhibitory reciprocal function between the orthographic and the phonological levels which derive from the orthographic
units. As we see from Figure 3 an individual letter activates the corresponding words, e.g. letter \( f \) activates groups of words such as \( \text{fine, fare, file} \); while letter \( i \) activates groups of words such as \( \text{file, fire, hire, wire} \); etc., however, given \( \text{fire} \) as input, this word is fully computed reciprocally into the connection network, and \( \text{fine, fare, file, and hire} \) are in the end inhibited while \( \text{fire} \) is reinforced and sustained. The strength of the interletter associations via interactive mechanism was commented by Adams (1990, p109) “The perceptual facilitation that may result from this architecture is substantial. It is, moreover, a classic case of the whole working better than the sum of its parts.”

The processing of activation is assumed to be innate and to interact with a learning ability, with potential pedagogical implication serving to strengthen or weaken connections through learning experience. Simulations of PDP networks claim to model the learning process of how children learn to read. Thus, this model acknowledges factors that provide the space for teaching methodology to play a role without being constrained exclusively by factors presumed by ODH.

A key distinction between PDP and DRC is summarized by Adams (1990, p107):

> within this framework (PDP), skilful word reading is held to depend, not just on the appearance or orthography of words, but also on their meanings and pronunciations...the single most important tenet within this modelling framework is that these three types of information (orthographic, phonological and semantic) are not processed independently of one another. Skilful reading is the product of the coordinated and highly interactive processing of all three.”

Taking account of the architecture of DRC, it is clear that this difference is reduced in recent models. Word reading in PDP as well as DRC is seen as a coordinated and interactive process available to readers at the cognitive level instead of just a by-product of orthographies predicted by the ODH.

2.2.1. Tasks on word reading related to PDP based phonological processing

The PDP idea of universal phonological processing being available to readers automatically and obligatorily, regardless of orthographic differences between languages with discussion of early phonological activation in Chinese word reading, as well as the extent to which phonology assists access to meaning (Fang et al. 1986; Perfetti et al. 1992; Perfetti & Tan 1997; Perfetti & Zhang 1991, 1995). The phonologically mediated priming paradigm has been used to investigate these issues, which are very relevant to our interest to contrast DRMs.

Experiments reported by Perfetti & Zhang (1991) adopted a backwards visual masking and unmasked priming paradigm to investigate the activation of phonological information in the process of reading Chinese. Semantic and phonological priming in the identification of masked characters were elicited
through the tasks. They used 40 speakers of Chinese from P.R.C., (5) age ranged from 20-40, to participate in the first task, 20 new subjects from the same target population in the second task; while 32 new subjects participated in the third and 20 new subjects in the fourth priming experiments. The sequence of backward masking visual presentation in the first experiment was a cohort of target words, a homophonic (1) or graphic mask (2) with 30 msec exposure and followed by a pattern mask. A semantic mask (3) was included in the semantic masked task. A control mask (4) was interspersed through the task. The sequence of the target in the second unmasked experiment was followed by a pattern mask without an intervening character mask. The third experiment was similar to the first one except that the target character was preceded by a prime instead of followed by a mask. The primes, however, were hand drawn in official script type so the visual similarity to the targets was reduced. The fourth experiment is a naming task with a similar procedure as the experiment three. This is illustrated in Table (8):

Table 8. Chinese backward masked priming task

<table>
<thead>
<tr>
<th>BACKWARDS MASKED PRIMING TASK</th>
<th>Target</th>
<th>Masks/Primes</th>
<th>Pattern mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>視 (shì) ‘see’ -&gt; 事 (shì) ‘business’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>視 (shì) ‘see’ -&gt; 現 (xiàng) ‘now’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>視 (shì) ‘see’ -&gt; 看 (kàn) ‘look’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>視 (shì) ‘see’ -&gt; 清 (qīng) ‘clear’</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The purpose of the first experiment is to investigate the reading of Chinese characters under different exposure times, which had been found to involve early phonemic activation in English word reading experiments. Subjects were told to identify the first character they saw and put it down in writing, which is the target character in the backward masked tasks (see Table (8)), but were encouraged to report both the first as well as the second character. The pattern mask stayed on the screen until the subject finished their response in writing. The accuracy of the identification level for the target characters ranged between 40% and 60% across the subjects. In this experiment, the graphic mask was found to prime better target identification than the other three types of masks, however, no evidence of prelexical phonemic effects was found(6).

The second experiment was carried out with a similar sequence that used in the first experiment except that the target character was presented after the mask character. This served as a comparison with the experiment in order to identify

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(5) The authors noted that Mandarin was not the native dialect of some subjects. They were graduates from various departments at the University of Pittsburgh and Carnegie Mellon University.

(6) The graphic mask effect was significant for both subjects and by items, p<.001
the masking effect on the processing of target character. The results show a higher identification level without a character mask, and therefore, substantiate the masking effect in the previous experiment. At this stage, the identification of the written characters did not appear to involve prelexical phonological processing. That means, the disruptive effect was reduced when the graphic mask character was displayed but neither with the phonemic nor semantic mask tasks. The authors suspected that the failure to locate early phonological effects might be due to the insufficient exposure time of the target and mask. In order to further clarify the role of phonemic processing as a ‘natural and automatic accompaniment of lexical access’ in Chinese word reading, a third experiment was conducted to look into phonemic activation through phonemic priming, that is, to investigate whether a target word can be facilitated by a phonemic prime character. As a modification of the first and the second experiments, the Chinese character masks were hand drawn in official script style, and have a lower and wider appearance, to reduce their visual similarity to the targets.

In the third experiment, the authors presumed that if a word’s phonemic shape is activated as an automatic part of its identification, the phonemic activation should be available the same time when the word is identified. A similar order was used to the first experiment except that the target character was preceded by a prime instead of a mask. The results showed that both phonemic and semantic priming effects were found at exposure of 50 msec but not at 20 msec. However, no phonemic mediation pre-lexically in Chinese word recognition was indicated, but the pronunciation seemed to be involved immediately after the word recognition. It was concluded that phonological information was immediately available as part of character identification as they did not find semantic effects preceding phonemic effects, which means their semantic activation did not occur before phonological activation in Chinese character recognition. A fourth experiment was conducted to further investigate phonemic processing in reading Chinese characters.

In the fourth experiment, a trial consisted of the exposure of a prime character for 180 msec, the aim being to provide sufficient exposure time for the identification of prime and target. This was followed immediately by a target character that remained exposed until the subject named the character\(^{(7)}\). Subjects were told to name the target character but not the prime. Due to the phonemic production encouraged by the naming task, it results in a clear phonemic priming effect at 35 msec\(^{(8)}\), while a smaller semantic priming effect at 18 msec but graphic priming effect was not found in this experiment.

The overall results support the finding that phonological processing is a product of the word’s identification since phonological information was found available as part of character identification in the experiments. This was summarized in the following statement by Perfetti & Zhang (op,cit, p642):

\([7] A Microphone was connected to a timer to record the latency between target exposure and the initial vocalization of the subject.

\([8] Compared to the previous experiment, where the authors found both phonemic and semantic priming effects at exposure of 50 msec but not at 20 msec.

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“arousing the familiar speech elements associated with the graphic system is a natural and probably automatic part of recognizing a word in any writing system.”

Though phonemic priming effect was not found activated pre-lexically in Chinese as English, yet it was observed that whenever there was semantic activation, there seems to be a phonological effect in the experimental paradigm. This is justified in the fact that without recognizing the target character, it certainly cannot be pronounced.

Further homophone and semantic judgment tests were conducted by Perfetti & Zhang (1995), who varied the exposure time for the stimulus over 90, 140, 260 and 310 msec. This adjustment is not only to ensure sufficient time exposure activation for both pronunciation and semantic cues, but also to determine how early pronunciation and the meaning were activated during the character reading. Participants were required to make judgments about the meanings of pairs of characters. Their reaction times and error rates to homophonic foils were recorded as evidence of phonological interference. The results showed that semantic interference in the homophone judgment task appeared only at 140 msec exposure time, but homophone interference in the semantic judgment task occurred at all four exposure times, which supports the meaning-with-phonology model according to which phonology is available as quickly as meaning, a contradiction to the prediction of the strong ODH for Chinese where homophone interference should not be observed in a semantic judgment task. The automatic activation of the phonology associated with characters supports the presence of phonological representations in working memory information processing. These accords with the PDP view that the use of phonological representations in working memory is not a question of writing systems, but a question of human language and information processing, and the involvement of phonological processing should be considered a cognitive universal: Chinese readers do not bypass phonology. Note that it must be acknowledged that the subjects participating in the experiment are from P.R.C. where pinyin is systematically taught prior to learning characters. Thus, it may be that pedagogical variant is a crucial factor for the meaning-with-phonology result.

An item of note is that the stimulus characters Perfetti and Zhang employed in their experiments were simplified characters as used in P.R.C. where the graphic composition has been simplified and the semantic cue might not be well preserved as the complicated characters used in HK and Taiwan. Accordingly, we might expect that the semantic effects activated in the tasks would be different from those in tasks where complex characters were employed. It is expected that a stronger semantic effect will be displayed when complex
characters are presented as a stimulus in the judgment task since original orthographic composition was preserved to provide semantic cues\(^{(9)}\).

A masked paradigm study to which the above observation does not apply was carried out by Hoosain & Peng (1995). Same tone homophone masks and complex characters were adopted. A mixture of 28 graduate students and visiting scholars, who were native speakers of Mandarin, took part in the experiment. Another 28 subjects with similar backgrounds participated in the second experiment. Both experiments followed the same procedure except that the first experiment adopted a 50 msec exposure duration to the target and 30 msec exposure to the mask which can be of four types (1) homophonic, (2) graphic, (3) semantic and (4) control. The second experiment extended the target and mask exposure durations to 60 msec and 40 msec respectively. Targets were also further divided into high and low frequency type. Examples of the different conditions appear in Table 16:

**Table 9. High and low frequency target masked tasks used by Hoosain & Peng (1995)**

<table>
<thead>
<tr>
<th>High-frequency target</th>
<th>Low-frequency target</th>
</tr>
</thead>
</table>

Subjects were informed about the sequence of stimulus presentation and were told to write down the target character as their response, a procedure that is similar to Perfetti and Zhang’s experiments. The results were found significant on exposure duration with phonological vs. semantic masks for high frequency targets. Generally, the graphic mask effects did not vary significantly with frequency or exposure durations across the two experiments. However, phonological activation occurred before semantic activation for high

\(^{(9)}\)It was observed that among the stimulus characters where homophones were categorized, one third of the homophonic masks in fact used different tones, of which suprasegmental feature defining semantic property of characters. The change of the tone indicates the change of the meaning. This was considered as another complication to be noted by the researcher.
frequency targets at both exposure durations. For the first result, it was reported that due to the original graphic features in the complex characters, the graphic mask effects had been activated more fully and strongly. The second result, the occurrence of phonological processing before semantic activation, can be attributed to the employment of phonologically similar target-mask pairings, where identical tones were used in the masks. The researchers attribute the pre-semantic phonological processing displayed by native Chinese readers to long-term practice and learning the association of script and sound. Once again this is a result consistent with the universal phonological processing assumed in PDP models.

A note of caution should be sounded regarding the idea that phonology activated in the process of reading a deep orthography like that of Chinese may well be different from that engaged by a shallow orthography, such as English. For Chinese, it is the syllable level that accompanies tone variation, while for English, individual phonemes are connected by GPC rules to letters or sequences of letters. A summary of the various levels of phonological processing that might be relevant to PDP based word reading tasks appear in Perfetti, et al. (1992). First, they maintain that there is automatic phonological activation that occurs in writing systems whether it is at the pre-lexical, or post-lexical stage. Secondly, phonological processing is mainly characterized by the extent to which it involves sub-lexical phonology, but not in terms of whether activation occurs at all. This acknowledges that the nature of phonological activation can vary with orthographic variation, but still be necessary. Finally, the activation of phonology may serve memory and comprehension though this activation is not consciously under readers’ control. Generally speaking, PDP based experiments emphasize that phonological processing involved in the word reading processing is a result of instructional effects.

3. Conclusion

Overall we observe that the elements of cognition and learning involved in the word reading process are modeled and explicitly explained in PDP as well as in the recent form of DRM, DRC. Both are consistent with the existence of their pedagogical implication in word reading. In this chapter, we have introduced two currently popular views on the mechanisms underlying word reading as well as the ODH and briefly reviewed some of the evidence that is supporting them. The conclusion indicates that that the latest DRM, DRC, has embraced the interactive component similar to PDP, thus are compatible with the existence of pedagogical implication as we intend to observe. Lastly, recent studies investigating PDPs have further suggested that phonological activation is an automatic accompaniment of word reading even for a deep orthography, such as Chinese. It was found a compatible factor with DRC with respect to its recent development and progress accounting to learners’ reading and learning experience. Thus, the evolution of DRM grows out of orthographic variation and achieves its capacity to illustrate word reading at universal level.
淺談雙程模式演進歷程及其教學相容度之探討

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摘 要

在世界文字體系當中，中文一直被視為是拼詞文字，而與拼音字母的英文有截然不同的特質。二者因字音字形相關對應的差異性，故中英文不同體系背景下的讀者，在文字閱讀行程上，也被認為是相對論。早期的雙程模式在本質上預設英文讀者慣性上會訴諸於字音行程，而中文讀者則傾向於運用字形行程來達成文字閱讀的認知和理解。然而在近期多方探索讀者認知行程的研究中，卻得到不同的論點。研究發現讀者雖具有不同文字體系背景，但字音行程的運用，卻是世界通行共用的認知模式。中文體系背景下（母語）的讀者可藉此認知模式，成功地學習英文（第二外國語）。本研究論文將淺談雙程模式的演進及其相關實驗，並逐步縱觀其他文字體系，進而針對中文體系的語言模式作探討。同時將引進平行互動模式作進一步的對比，目的在提供讀者了解有關語言心理學中文字行程模式的背景，並解析文字閱讀的認知和理解過程中，認知行程對讀者字音字形使用過程的影響，最終目標是要捕捉雙程模式在文字閱讀演進歷程中，如何融合互動模式的內因，並進一步在教學法相容度特質上，闡述讀者如何運用世界共用的認知行程來主導他們在母語和第二外國語文字閱讀行程上的學習。

關鍵詞：雙程模式、平行互動模式、字音字形相關對應、字音行程、字形行程