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Brief article

Reading Chinese characters for meaning: the role of phonological information

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Abstract

Two experiments with the Stroop paradigm were conducted to investigate the role of phonological codes in access to the meaning of Chinese characters. Subjects named the ink color of viewed characters or color patches. Key items were color characters, their homophones with the same tone, homophones with different tones, and semantic associates. Apart from finding the usual Stroop interference effect, homophones produced significant interference in the incongruent condition, provided that they had the same tone as the color characters. The interference effect from homophones, however, was significantly smaller than that from color characters. Semantic associates generated an interference effect in the incongruent condition, an effect of the same magnitude as the effect from the same-tone homophones. Finally, in the congruent conditions, all the key items yielded facilitations compared to neutral controls, though the facilitation from color characters was larger than the facilitations from other types of characters. These findings suggest that phonological codes in Chinese are activated obligatorily and provide early sources of constraint in access to meaning. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

How does visual-orthographic and phonological information of a written word contribute to its identification and meaning activation? This question has provoked a

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large body of research over the past 2 decades (Berent & Perfetti, 1995; Coltheart, 2000; Coltheart, Curtis, Atkins & Haller, 1993; Frost, 1998; Rayner & Pollatsek, 1989; Taft & van Graan, 1998; Van Orden, Pennington & Stone, 1990). The variety of the forms of writing systems and the intriguing possibility of cross-linguistic differences in lexical processing have added to the controversy (e.g. Frost, Katz & Bentin, 1987; Grainger & Ferrand, 1996; Lukatela & Turvey, 1998; Pollatsek, Tan & Rayner, 2000; Wydell, Patterson & Humphreys, 1993; Ziegler, Tan, Perry & Montant, 2000). In this article, we report two experiments with Chinese characters, the basic writing units in a logographic system, to elucidate the role of phonological and orthographic codes in access of meaning.

A popular viewpoint of Chinese reading has been the direct access hypothesis, according to which the Chinese reader arrives at the meaning system by recourse to a visual-orthographic pathway, without associating with characters' phonology (Baron & Strawson, 1976; Shen & Forster, 1999; Tzeng & Hung, 1978; Wong & Chen, 1999). This hypothesis has been deeply ingrained, mainly because it concords with some linguistic analyses of the Chinese language. As a morpho-syllabic writing system, the Chinese graphemic structure maps onto meaningful morphemes rather than phonemes in the spoken language. Thus, a character has a more direct association with its meaning than a printed English word does, while its association with phonology is rather arbitrary and only defined over the character to syllable level.

Contrary to the direct access hypothesis is a class of models that assume that activation from graphic forms to meaning and from graphic forms to phonological forms to meaning occurs in parallel (Xu, Pollatsek & Potter, 1999). Links between phonological form and meaning can then produce meaning activation that is indirectly 'mediated' through phonology. One such model is the Interactive Constituency Theory (ICT) (Perfetti & Tan, 1998, 1999; Tan & Perfetti, 1997, 1998). The ICT assumes that a phonological form is routinely activated as part of word identification (Perfetti, Zhang & Berent, 1992) because it is a constituent of the identified word. This phonological activation is rapid and may precede the direct activation of specific word meaning in many situations. However, the ICT further assumes that phonological activation is diffuse across characters sharing the same pronunciation (Tan & Perfetti, 1997). Because homophony is pervasive in Chinese, the diffusion assumption implies relatively large networks of interconnections between a single phonological unit and numerous related meaning nodes. This diffusion effect limits the effectiveness of phonological activation in meaning tasks.

Evidence to date appears consistent with the parallel activation hypothesis, although there remains a question about critical details concerning visual form. Using a semantic categorization procedure (Van Orden, 1987), Leck, Weekes and Chen (1995) asked subjects to decide whether a target character belonged to a pre-specified category. Both visually similar non-homophones and visually similar homophones took longer to reject for compound targets. Visually dissimilar homophonic foils, however, were not more difficult to reject than controls. These findings may indicate that the direct access route plays a dominant role in access to meaning, whereas the interference caused by phonological identity hinges on visual similarity (see also Zhou & Marslen-Wilson, 1999).

However, other studies have reported more general effects of phonology on access to meaning that do not depend on visual-orthographic similarity. Perfetti and Zhang (1995) found phonological interference in meaning judgments for pairs of one-character words that generally were not graphically similar. Tan and Perfetti (1997) reported that naming a target character was facilitated by a prime that was a (visually dissimilar) homophone of its semantic associate, provided the number of homophone characters was relatively small. In a semantic relatedness decision task, Xu et al. (1999) found significant interference from a homophone of a target word that was semantically related to an initially exposed cue word, regardless of the visual-orthographic similarity of the homophone to the target. In addition, Xu et al. (1999) observed that visually similar non-homophones were also more difficult to reject than controls. Chua (1999) asked the subject to judge whether a target fit a definition. The result was that a single character homophonic with the target was harder to reject than its control, whether or not it had visual-orthographic similarity to the target. Interestingly, Chua (1999) found that a single character that was an orthographically similar non-homophone of the target was not more difficult to reject, suggesting that interference based on visual-orthographic similarity depends on phonology.

The aforementioned studies of the role of phonological codes in meaning activation seem to have generated a consensus result – that phonology is activated in a meaning task at least in some circumstances. The differing results relate to the question of whether the contribution of phonology in meaning performance is independent of orthographic form. In the present experiments, we take advantage of the facts that homophones are abundant in Chinese and many homophones have no visual-orthographic similarity to explore the automaticity of phonological activation in meaning access. A Stroop color-word task was adopted (Stroop, 1935), which required subjects to name the ink color of Chinese characters. Previous research with English has demonstrated that naming the ink color of incongruent color words (e.g. *red* written in green) took longer than naming the ink color of neutral word controls. This effect, the *Stroop interference effect*, exemplifies unintentional automatic word reading (for reviews see Logan, 1988; MacLeod, 1991). Research has also shown that naming latency is shorter for congruent color words (e.g. *green* written in green) compared with neutral word controls, which is usually referred to as the *Stroop facilitation effect*. When the Stroop paradigm is applied to investigation of phonological coding in access to meaning, researchers often present subjects with pseudohomophones, such as *bloo*, and ask them to name the color of printed letter strings (e.g. Besner & Stolz, 1998; Dennis & Newstead, 1981; Tzelgov, Henik, Sneg & Baruch, 1996). All of these studies reported that letter strings like *bloo* retarded performance substantially when they were incongruent with the color that had to be named, suggesting that subjects had computed the phonological code of pseudohomophones and used it to access (color words') meaning.

In the present experiments, both color characters and their homophones without visual similarity to color characters were used as key stimuli. Experiment 2 also used semantic associates of color characters, in addition to homophones. We expected to demonstrate the Stroop interference effect for color characters, an effect reported in previous studies with Chinese (e.g. Biederman & Tsao, 1979; Lee & Chan, 2000). However, we were most interested in exploring the effect from homophones. If meaning access is constrained by both orthographic and phonologic activation, as predicted by the parallel activation hypothesis, then we would expect that the homophones of color characters also interfere with color naming, though color characters produce more interference than homophones. These predictions implicate phonology and contrast with the prediction from the direct access hypothesis that homophones should not interfere with color naming. The addition of semantic associates of color words (e.g.血, *blood* for red) would allow us to ascertain whether meaning matters in color naming, because effects of semantic associates will be based on activation along semantic links.

Chinese (Mandarin) as a tonal language uses four different tones as suprasegmental phonological features. Thus, an additional question for phonological processing is the involvement of tone information. At some point, a full specification of a phonological syllable must include its tone as well as its segments (consonants and vowels). However, it is not obvious that tone specification is critical in the kinds of rapid phonological effects observed in single character experiments. Available evidence indicated that homophones produced interference effects in the Van Orden task, provided that they had both identical phonetic information and identical tones as targets (Xu et al., 1999). The present experiments used two types of homophones: homophones having the same phonetic (consonant and vowel) and tonal information as the color characters, and homophones having the same phonetic (consonant and vowel) but different tonal information as the color characters. This manipulation would allow us to determine whether the intriguing findings of Xu et al. (1999) could be generalized to the present Stroop paradigm. More generally, research on tone will help us to understand the internal structure of a phonological code (Berent & Perfetti, 1995; Birch, Pollatsek & Kingston, 1998).

2. Experiments 1 and 2

2.1. Method

2.1.1. Participants

Forty-five native Chinese (Putonghua) graduate students participated in the present experiments, 20 for Experiment 1 and 25 for Experiment 2. All had normal or corrected-to-normal vision.

2.1.2. Materials

The Chinese stimuli are shown in Fig. 1. In order to fairly assess the possible effect of homophones, the four neutral characters were matched with two sets of homophones for visual complexity (as measured by stroke number) and frequency. Homophones were not visually similar to color characters.

Condition	Color characters	Same-tone homophones	Different-tone homophones	Semantic associates	Character controls
Character	红	洪	轰	血	贯
Frequency and stroke number	592, 6	50, 9	64, 8	310, 6	74, 9
Meaning	red	flood, big	boom	blood	pass through
Pronunciation	/hong2/	/hong2/	/hong1/	/xue3/	/guan4/
Character	黄	皇	晃	金	奖
Frequency and stroke number	281, 11	62, 9	59, 10	384, 8	51, 9
Meaning	yellow	emperor	sway	golden	prize
Pronunciation	/huang2/	/huang2/	/huang4/	/jin1/	/jiang3/
Character	蓝	栏	览	天	华
Frequency and stroke number	106, 13	39, 9	36, 9	3090, 4	36, 6
Meaning	blue	fence	view	sky	cream
Pronunciation	/lan2/	/lan2/	/lan3/	/tian1/	/hua2/
Character	绿	虑	旅	草	涂
Frequency and stroke number	178, 11	85, 11	90, 10	444, 9	81, 10
Meaning	green	ponder	travel	grass	scrawl
Pronunciation	/lü4/	/lü4/	/lü3/	/cao3/	/tu2/

Fig. 1. Chinese characters used in Experiments 1 and 2. Note. The numeral following the pronunciation refers to tone. Frequency count is in terms of the Modern Chinese Frequency Dictionary (1986). Semantic associates were used only in Experiment 2.

2.1.3. Procedure

The stimuli, each approximately 1.6 cm wide by 1.8 cm high, were presented on a color monitor interfaced with an IBM computer. Participants were required to name the color of the stimulus exposed as quickly and accurately as possible, the time between stimulus onset and response onset being the naming latency. There were 20 practice trials divided equally between the conditions.

In Experiment 1, participants responded to 144 test trials divided into two blocks of 72. Each set of 72 trials included 12 congruent trials (four for color characters, four for same-tone homophones, and four for different-tone homophones), 36 incongruent trials (12 for each of the three types of key characters), 16 trials for neutral characters, and eight trials for color patch controls. In Experiment 2, participants responded to 192 test trials divided into two blocks of 96. Each set of 96 trials included 16 congruent trials (four for color characters, four for same-tone homophones, four for different-tone homophones, and four for semantic associates), 48 incongruent trials (12 for each of the four character types), 16 neutral character trials and 16 color patch trials. In both experiments, the incongruent trials used every combination of characters and colors except the congruent combination. Each of the two blocks was randomized separately.

2.2. Results

Naming times beyond 1200 ms were excluded (less than 2%). The mean reaction times, standard deviations, and the error rates of responses for each condition are presented in Table 1.

We calculated the facilitation by subtracting reaction times in the congruent conditions from reaction times in the neutral conditions and calculated interference by subtracting reaction times in the neutral conditions from reaction times in the incongruent conditions (see Logan & Zbrodoff, 1998). In Experiment 1, relative to the neutral character controls, we found facilitation effects of 90, 63, and 45 ms for color characters, identical-tone homophones, and different-tone homophones, respectively. All these effects were significant ($Fs(1, 19) > 12.61$, $Ps < 0.002$). When compared with color patch controls, however, only color characters yielded significant facilitation ($F(1, 19) = 29.90$, $P < 0.001$). In Experiment 2, facilitation effects were somewhat smaller than those in Experiment 1, i.e. 70, 34, 33, and 22 ms effects for color characters, same-tone homophones, different-tone homophones, and semantic associates, respectively, relative to the neutral character control. But as with Experiment 1, all these effects were significant ($Fs(1, 24) > 6.33$, $Ps < 0.02$). Again, when compared with the color patch controls, only color characters produced significant facilitation ($F(1, 24) = 20.57$, $P < 0.001$). In both experiments, congruent color characters produced larger facilitation effects than did their homophones (regardless of tone) and associates ($Fs > 5.65$, $Ps < 0.03$).

Likewise, we also computed the Stroop interference effects. For Experiment 1, we obtained 78, 28, and 0 ms of interference (relative to neutral character controls) for color characters, same-tone homophones, and different-tone homophones, respectively. For Experiment 2, we found 58, 29, 12, and 30 ms of interference for color characters, same-tone homophones, different-tone homophones, and semantic associates, respectively. These effects were all reliable ($Fs > 8.96$, $Ps < 0.007$) except for homophones with different tones. The interference effects were even greater when compared with the color patch controls. Equally important is that incongruent color characters produced significantly larger interference effects than their homophones and semantic associates in both experiments ($Fs > 10.41$, $Ps < 0.005$). Moreover, in both experiments, reaction times in the neutral character conditions were significantly slower than reaction times in the color patch conditions ($Fs > 20.30$, $Ps < 0.0001$).

Error rates showed the same pattern as reaction times. Interference from color characters and same-tone homophones was significant relative to neutral characters in both experiments ($F > 18.18$, $P < 0.001$). Different-tone homophones produced more naming errors in both experiments, but this difference was more reliable in

Experiment 2 ($F(1,24) = 6.52$, $P < 0.02$) than in Experiment 1 ($F(1,19) = 3.11$, $P = 0.094$). Semantic associates interfered more than neutral characters, but not at a high level of reliability ($F(1,24) = 3.36$, $P = 0.08$). In Experiment 1, color characters and different-tone homophones facilitated color naming in the congruent conditions ($Fs(1,19) > 5.63$, $Ps < 0.05$). There were no significant facilitation effects in the congruent conditions for Experiment 2.

3. Discussion

The results of the two experiments are consistent and clear-cut. First, the usual Stroop interference effect was found, suggesting obligatory activation of lexical information, and confirming the findings of previous studies using this paradigm (e.g. Biederman & Tsao, 1979).

Second, homophones of color characters also produced a significant interference effect in the incongruent condition. This suggests that phonological codes of Chinese characters have been activated and are involved in the access of character meanings. Because it is in the interest of task performance to suppress phonological information, the failure to do so suggests an unintentional, obligatory activation of phonologic information. As to whether tone information is part of the functional phonological code in this situation, the interference evidence was more robust for homophones with the same tone than for homophones with a different tone. Same-tone homophones produced reliable interference in both error rates and naming latencies, whereas different tone homophones produced interference only in error rates, and with high reliability in only one of the two experiments. Thus, based on interference data alone, a Chinese character's phonological code appears to include both phonetic information (consonant and vowel) and tonal information, in effect a full phonological specification of the character. This interpretation is consistent with the findings of Xu et al. (1999) in the semantic relatedness paradigm.

However, the data of the homophone facilitations in the congruent conditions suggest a different picture. In Experiments 1 and 2, all homophones aided in color naming, although the same-tone effects appeared slightly larger than different-tone effects in Experiment 1 (only). It is not clear why the patterns of facilitation and interference diverge on the question of tone. However, one possibility is that facilitation, which occurs in a rapid performance event, can benefit from segmental phonologic information only. Either the onset of the syllable, or the full phonemic sequence, both of which are the same in the homophone and the color character, can participate in facilitation as the character's phonology is activated. Interference, which is part of a slower performance event, may be more immune to segment-only incongruence. On this conjecture, segmental information might be activated more quickly than tone information, even though both components are required for a complete specification of phonology. It is likely that the full specification, segment plus tone, is what constrains meaning activation and hence produced the most reliable interference. Segment specification alone, however, is available to assist a

Table 1
Mean naming latencies (in ms), error rates, and standard deviations (in parentheses) as a function of congruity and character type[a]

Experiments	Conditions									
	Congruent color characters	Congruent homophones of the same tones	Congruent homophones of different tones	Congruent semantic associates	Incongruent color characters	Incongruent homophones of the same tones	Incongruent homophones of different tones	Incongruent semantic associates	Character controls	Color patches
Experiment 1										
RT (SD)	642 (90)	669 (101)	687 (108)	–	810 (74)	760 (90)	732 (81)	–	732 (84)	695 (84)
ER (%) (SD)	0.00 (0.00)	0.63 (2.80)	0.00 (0.00)	–	12.71 (6.82)	6.04 (5.97)	3.04 (3.76)	–	1.21 (2.29)	0.88 (2.16)
Experiment 2										
RT (SD)	617 (64)	653 (101)	654 (68)	665 (80)	745 (52)	716 (67)	699 (82)	717 (66)	687 (60)	654 (63)
ER (%) (SD)	0.00 (0.00)	0.50 (2.50)	0.57 (2.86)	0.00 (0.00)	13.33 (8.25)	5.33 (4.74)	2.78 (4.33)	2.50 (4.66)	0.82 (2.48)	1.50 (3.95)

[a] RT, reaction time; SD, standard deviation; ER, error rate.

rapid process of the kind that it is present for facilitation (see also Taft & Chen, 1992).

A further important finding was that color characters produced larger effects than homophones (with and without the identical tone) – more interference in the incongruent conditions and more facilitation in the congruent conditions. This result has a straightforward interpretation in the ICT. Meaning activation is stronger on the basis of a unique combination of orthographic and phonological constituents than from only a shared phonological constituent. Thus, the character 绿, pronounced /lü4/ and meaning 'green', provides maximal interference and maximal facilitation because it directly activates a meaning that can be either congruent or incongruent with the color to be named. The character 虑, also pronounced /lü4/ and meaning 'ponder', provides indirect facilitation and interference through its phonological link to the meaning 'green'. It is the unique combination of character constituents – orthography, phonology, and meaning – that fully defines the lexical entry of a character.

Finally, we found that the semantic associates of color characters retarded color naming in the incongruent condition and speeded up color naming in the congruent condition. This indicates the role of lexical-meaning links in word processing. The meaning of a semantic associate is activated by the orthographic and phonological pathways. This meaning activation can spread, probably to a limited set of semantically related words (Balota, 1983; Neely, 1977), including the color character. However, the effects of semantic associates were smaller than those of color characters. Again, as with the homophone activation, this fact arises because the semantic activation process is an indirect process, intrinsically weaker than the activation of relevant meaning by the color character itself. Just as the homophone had only the shared phonological unit that leads to indirect access to meaning, the meaning associate had only the shared meaning node. We note that our account that character meaning matters in color naming is also bolstered by the data that naming latencies from neutral characters were longer than naming latencies from color patches.

In summary, our findings suggest that phonological information of Chinese characters is obligatorily activated and used to activate character meaning in reading. Further, our data show that tonal information is part of the phonological code and plays a role in Stroop interference. Our data are important because they cannot be explained by the direct access hypothesis. Rather, they provide further corroboration of the parallel activation hypothesis, according to which there are two pathways in access to meaning, one directly from orthography to meaning and the other from orthography to phonology to meaning.

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