Leading-edge Research or Lost Cause?: The Search for Interscriptual Stroop Effects

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What is "Stroop Interference?"

The original version of the Stroop test, developed by J. R. Stroop in 1935 (Stroop, 1935), was done with a color-naming/word-naming task to study cognitive processing mechanisms for visual and verbal stimuli. In the original test by Stroop, subjects were presented with incongruent color words, for example BLUE printed in red ink (i.e., BLUE), and were asked either to name the color (in this case "red") or read the word (in this case "blue"). The original version of the Stroop test revealed that subjects took longer and made more errors when naming colors than when reading color names printed in black i.e., BLUE) or naming the color of color patches (i.e.,■).[1] Experimenters measured the time difference between the presentation of the color-word and the subject's response to a color-naming or word-reading instruction and called the measure that of "Stroop interference" or the "Stroop effect."

The theory behind the test was that in order to respond to a Stroop stimuli, in which visual and verbal material are presented together but are not congruent, subjects may need to go through a series of cognitive steps such as encoding verbal stimuli, encoding visual stimuli, comparing the visual and verbal material, selecting a response and executing it. Because the tests consistently showed that there were significant differences between the response times of subjects in color-naming and word-reading tasks, researchers hypothesized that there may be some kind of interference between the processing of the visual and the verbal information. The ensuing questions were where and why does the interference take place and what do the answers to those questions tell us about human information processing?

Since 1935, researchers have conducted studies using Stroop interference tests both to look for answers to questions about the processes behind the Stroop effect and to explore other cognitive processes. (For a review of the first three

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decades of work, see Jensen and Rohwer, 1966.) Stroop himself hypothesized that the interference occurs when a subject is in the process of selecting a response to a prompt to name a color or word. More recently, Keele (1972) supported the hypothesis that the interference takes place during the response process, when he found his subjects exhibited a Stroop effect both when they responded to Stroop stimuli physically (by pressing a key) as well as when they responded verbally. Seymour (1974) discussed the possibility that the interference may occur in the comparison stage if incongruous visual/verbal stimuli cause the subject to judge the "truth" of the match between the semantic meaning in a visual display and the display itself. For example, if "Above" is printed above "Above," the match is true; however, if "Below" is printed above "Above," the match is false as shown to the right. Seymour's intention was both to give additional evidence of the locus of Stroop interference and to use that evidence to further the understanding of the cognitive processes involved when readers are comparing sentences and pictures.

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Another example of the application of the Stroop paradigm is the study of hemispheric lateralization by Morikawa (1981), who compared the Stroop effect of Japanese reading logographic and syllabic Japanese characters with identical pronunciation. Because there were signficiant differences in the amount of Stroop effect subjects exhibited when reading these different kinds of characters, Morikawa placed the locus of Stroop interference in the encoding (perceptual) process and used his results to support the hypothesis that different cerebral hemispheres are responsible for processing different kinds of stimuli. In addition to the studies mentioned above, researchers have used Stroop tests to explore other areas of language processing such as automaticity of word recognition (Liu, 1973; Samuels, 1976; Schandler and Thissen, 1981) and speech recoding in reading (Martin, 1978; Naish, 1980). Many of the Stroop studies have had the dual purpose both of developing understanding of the processes and furthering the effort to pinpoint the locus of Stroop interference.

A Comparison of Cross-Orthographic Stroop Studies

In his recent text, Coulmas (1989) distinguishes the relationship between writing and speech: "Every writing system makes a selection of the linguistic units to be graphically represented (not language specific). [The units selected might be, for example,] words, morphemes, syllables, phonemes [or] phonetic [elements]. Every script makes a specific selection of the possibilities of a given [writing] system in accordance with the structural conditions of a given language. [Examples of such selections are] Chinese script, Arabic script, [and] Greek script. Every orthography makes a specific selection of the possibilities of a script for writing a particular language in a uniform and standardized way, [for example,] Chinese/Taiwanese orthography [or] Standard German/Swiss-German orthography." These distinctions are useful here to point out that studies across orthographies do not look just at a writing system, or at a particular style of script but rather look at specific manifestations of a script type as orthographies that have been adapted and conventionalized in particular cultural, social and temporal settings.

Along with single language Stroop studies, cross-language, and in particular cross-orthographic Stroop studies have been used for a number of different research goals, ranging from exploring specific cognitive processes, such as Morikawa's (1981) hemispheric lateralization study, to promoting more general hypotheses, such as the idea that reading different types of scripts might activate different kinds of cognitive processes (e.g., Fang et al., 1981; Hung and Tzeng, 1981). Researchers using variations of the original Stroop test to study the cognitive processes of readers of different orthographies have studied:

- languages represented by logograms, such as Chinese,
- languages represented by the Roman alphabet, such as English and Spanish,
- languages represented by combinations of systems, such as Japanese, which uses both logograms [*kanji*] and phonetic symbols [*kana*],[2] and Korean, which uses logograms, a phonetic syllabary [*hangul*] and romanization.

One of the first Stroop studies to compare a language represented by logograms (Chinese) with a language represented by an alphabet (English) was by I. Biederman and Y. Tsao in 1979. In their study, the authors found that their Chinese subjects exhibited significantly greater Stroop interference in naming the color of incongruent color words than did native English speakers in an equivalent English version of the same test. The differences between the Chinese and English speakers were unexpectedly large, in both the experimental and the control conditions. Biederman and Tsao speculated that their Chinese subjects had larger Stroop effects because "there may be some fundamental differences in the perceptual demands of reading Chinese and English which can have widespread implications for human information processing." Specifically, they suggested that because both the perception of color and the recognition of meaningful patterns (i.e., logograms) are processes attributed to the right cerebral hemisphere, the large Stroop effect exhibited by their Chinese subjects may have been due to competition for the same perceptual capacity.[3] (Generally, language processing is attributed to the left hemisphere.)

Although these explanations are provocative enough in themselves, Biederman and Tsao supposed further that Chinese readers may automatically activate configurational processing of logograms when reading, unlike readers of English who, according to Biederman and Tsao, automatically activate an abstract sound-to-grapheme rule system when reading. To support their hypothesis that there may be fundamentally different perceptual demands in the reading of languages represented by logograms and alphabets, Biederman and Tsao also cited a "widespread belief" that Chinese characters might provide more direct access to meaning than English words, quoting W.S. Wang's well known article on the Chinese language (1973): "To a Chinese the character for 'horse' means horse with no mediation through the sound 'ma.' The image is so vivid that one can almost sense an abstract figure galloping across the page."

马

Mā (Horse), simplified character

Biederman and Tsao finally supposed that their Chinese subjects exhibited such large Stroop effects in both experimental and control conditions because the predisposition of logographic readers toward visual imaging of printed information may be the "more natural."

Although subsequent researchers have acknowledged that Biederman and Tsao's hypotheses are intriguing, most are quick to point out the flaws in the study and to underscore that there is no support for a cognitive base to the claim that, for normal readers, the orthography used for Chinese languages provide more direct access to a meaning than does the orthography used to represent English. In the following sections, I discuss potential rival hypotheses to

Biederman and Tsao's conclusions by reviewing the study in the context of related research. I point out both the importance and the sometimes subtle nature of these rivals by specifically focusing on the selection of test materials, the bilingualism of subjects and issues of phonological recoding in reading.

Selection of Test Materials

Like many cross-orthographic researchers, Biederman and Tsao seem not to have controlled for the equivalence of their test stimuli across languages. An obvious lack of equivalence, for example, is in syllable length of words: two of the color words they choose are bi-syllabic in English ("yellow" and "purple") and monosyllabic in Chinese ("huang" and "zi"). Biederman and Tsao also claimed that the color words they selected, blue and green along with yellow and purple, have equal "focal" status in Chinese and English, a supposition for which they gave no evidence and which is questionable at best. Consider, for example, the cultural differences in the symbolism of "yellow": in China, yellow is the color of royalty; in American culture, yellow is more often asssociated with the idea of "cowardliness." Another example is that of the color "green": to Americans "green" is quickly associated with the notions either of "Earth" or perhaps of jealousy or money, while in China it is the symbolic color for youth. Arguments about the potential of rival hypotheses based on cultural factors could clearly be greatly extended here but these few examples are enough to point out here that these kinds of amorphous elements could effect the soundness of experimental results.

Another absence in the Biederman and Tsao study was the lack of control for the size of the test stimuli used in the experimental conditions. This variable should be mentioned at the very least, considering results of research in readability and document design that support the relationship between legibility of print and the ability of readers to comprehend text (Smith, 1979; Rehe, 1981). The essence of this research (which comes from investigations of human factors and document design rather than reading research) is that for some readers information printed in small type sizes is more taxing to read and is not remembered as easily or accurately as information printed in easily legible type. Putting issues of automatic word recognition in the background for a moment, in the case of these cross-orthographic studies one could argue that it might take any reader a few milliseconds longer to recognize the traditional character for *lan* 'blue' (18 strokes) than to recognize "BLUE" or even to recognize the character for *hong* 'red' (9 strokes) (both shown to the right) than to recognize "RED."[4] In addition, using a variation of the original Stroop stimuli, Besner and Coltheart (1979) have shown that skilled readers of English use different mechanisms to read numbers and words and that these mechanisms seem to be affected by the physical size of presented stimuli, but only when the numbers are presented logographically (e.g., 1 1, 2 2), not alphabetically (e.g., one one, two two). Considering that there is evidence suggesting that subject responses to logographic stimuli in Stroop conditions may be affected by the size and legibility of the characters, the lack of mention of the size of test stimuli somewhat weakens Biederman and Tsao's conclusions.

藍

Lan (Blue), 18 strokes, traditional character.

紅

Hong (Red), 9 strokes, traditional character.

Many cross-orthographic researchers have avoided this weakening factor by at least attempting to control for equivalence in cross-language test materials (for examples see Chu-chang and Loritz, 1977; Fang et al., 1981; Chen and Ho, 1982; Zhang and Simon, 1985). Many of these subsequent studies include examples of the actual Chinese logograms used as stimuli and/or specify the size of the characters that were presented, thus avoiding possible rival hypotheses about legibility of complicated characters. In attempting to control for as many factors as possible to make test stimuli equivalent, researchers also began to acknowledge the difficulty in truly controlling for linguistic, semantic or other levels of equivalency; for example, even if a single character Chinese word appears to be monosyllabic, it is so only "in nature" because Chinese words have tone which either lengthens or shortens their articulation (Fang et al., 1981). Though variations in visual complexity, number of syllables and "focal status" of words in cross-orthographic Stroop studies may not have profound effects on results, controlling for them can reduce the potential for a study's results to be questioned on these grounds.

Bilingualism and Stroop Effects

Another deficiency in the Biederman and Tsao study is the lack of sufficient discussion of the bilingualism of their subjects. Biederman and Tsao briefly consider bilingualism as a possible explanation for the differences of the Stroop results of their Chinese and English subjects, but rule it out by showing similarities between their results and data from other cross-language (but not cross-orthographic) Stroop studies (Preston and Lambert, 1969; Dyer, 1973), and by showing how various statistical analyses could smooth out the unusually large differences between the results of the Chinese and English subjects. Their explanations did not, however, touch upon a number of facets of bilingualism which, if considered, might show bilingualism as a significant cause of the unusually large Stroop effect exhibited by Chinese subjects.

For example, in their report Biederman and Tsao note only that their Chinese subjects were "native speakers of Chinese" from Taiwan; they do not specify that their subjects are all native speakers of Modern Standard Mandarin, the language in which the experiments were almost surely conducted. Although generally all Chinese students on the graduate level can speak and understand Modern Standard Mandarin, it is very likely that some of the subjects were native speakers of one of the several Taiwan topolects (e.g., Fujianhua) rather than Mandarin; Mandarin then would be the second language for these subjects, and English the third. Some part of the strong latency in the Chinese data may reflect interference between the subject's encoding of the experimental and control stimulus first in their native dialect and then transposing it into Mandarin, again certainly the requested language for the experimental response.

Hung and Tzeng (1981) commented on the lack of adequate attention to the issue of bilingualism in the Biederman and Tsao study, but say that the study should be replicated with a more general subject population. In a follow-up study to his 1981 paper on Stroop effects with Japanese readers, Morikawa (1987) explored reasons why Biederman and Tsao's Chinese subjects had such dramatic Stroop effects in both experimental and control conditions—but did so by testing a more specific rather than a more general subject popluation. Morikawa supposed that one possible reason the Biederman and Tsao bilinguals had such high interference measures might be because they were not in their native language environment. To test this idea, Morikawa conducted Stroop tests with Koreans reading alphabetic, syllabic or logographic representations of their language. Half the subjects were Korean university students in Korea, the others were Korean students in Japan. When Morikawa found no significant difference between his two subject groups, he discounted the possibility that environment could be an influencing factor in the Biederman and Tsao results and took his investigation of that point no further.

In a related study of bilingualism, Fang et al. (1981) conducted modified Stroop color-naming tests with Chinese-English bilinguals in which the stimulus and response languages were either the same or different. Their purpose was to see whether bilinguals would exhibit as much Stroop effect if the written forms of the two languages they were switching between were orthographically similar (i.e., English and Spanish, both alphabetic) or different (i.e., English and Chinese, Chinese being logographic). Their results showed not only that subjects had greater within language interference than between language interference, but also that there was an inverse relationship between amount of interference and degree of similarity between orthography of the two languages. In other words, the findings of Fang and his colleagues showed that the more similar the orthographies of the two languages of a bilingual, the more interference he or she is likely to exhibit in processing incongruent color words. Fang and his colleagues did suggest that there may be fundamental differences in the processing mechanisms of languages represented by logographic and alphabetic orthographies, but their conclusions seemed considerably more constrained than Biederman and Tsao's and, therefore, more credible because they did not inflate their claims to suggest that one orthography may be "more natural" than another or may be capable of triggering specific kinds of cerebral processing.

Another aspect of bilingualism not addressed by Biederman and Tsao was taken up by Chen and Ho (1986) in their study of reverse Stroop effects. In their review of bilingual Stroop studies, Chen and Ho note that the longer subjects have been working in a second language environment, the less Stroop interference they exhibit with materials in their first language and the more interference they show with materials in the second language they are acquiring. If one inspects the Biederman and Tsao data, it seems quite possible that their subjects may have differed widely in their degrees of bilingualism not only because they specifically mention that their subjects were bilingual "to varying degrees" but also because there was a wide distribution of response times within their Chinese subject group, with only six of sixteen subjects equally distributed around the mean. Therefore, it seems possible that Biederman and Tsao's subjects may have differed so widely in their response times to Stroop stimuli due to different levels of adaptation to working with alphabetic language materials and/or individual differences in degree of proficiency in Mandarin Chinese. In studies across languages and orthographies, then, the language background and proficiency of subjects, slippery parameters themselves, may also be important, if not critical, factors to attempt to take into account.

Speech Recoding, Short-Term Memory (STM) and the Stroop Effect

Biederman and Tsao's interest was whether the "application of a system where the names were directly associated to the configuration of the stimuli, as in Chinese, would result in more Stroop interference than the application of an abstract sound-to-grapheme rule system," as exists for English. Prior to Biederman and Tsao's study, however, several researchers had already investigated the relationship of sound-to-grapheme in various orthographies and implications of those relationships to visual information processing (Chu-chang and Loritz, 1977; Erikson et al., 1977; Tzeng et al., 1977). These earlier investigations all explored speech or phonetic "recoding" in reading. Biederman and Tsao, however, touch upon the notion of speech recoding only as a rhetorical step in their argument that there may be fundamental differences in the perceptual demands of reading Chinese and English. They do not take up the issue of speech recoding nor the possibility that Chinese readers may rely—to some degree at least—on the recoding of print information into sound en route to meaning. The acknowledgement of this possibility may have led Biederman and Tsao to reconsider their hypothesis.

When Biederman and Tsao wrote their 1979 article, the investigations of speech recoding by cross-language researchers had yielded some strong evidence that was counter to their argument of the primacy of visual encoding in the processing of logographic characters. For example, independent studies with native readers of Japanese (Erikson et al., 1977), Chinese and Spanish bilinguals (Chu-chang and Loritz, 1977), and Chinese alone (Tzeng et al., 1977) together provided strong evidence that proficient readers of these orthographies use phonetic mediation in reading, though the readers' awareness of their use of phonetic recoding differed. These studies all tested subjects' recall of homophonic and non-homophonic words, finding that subjects recalled non-homophonic words better than homophonic sets of words regardless of orthography, indicating that sound as well as sight may play a part in storing the word sets in memory of written language.

Specifically, these studies linked phonetic activity in reading to the functioning of short term or "working" memory (STM). For example, Erikson and his colleagues (1977) theorized that readers use a phonetic storage in STM to hold information while other linguistic processes are going on. This phonetic "buffer" or "workspace" in memory may be necessary as a place "in which a representation of a sentence can be stored and updated during the course of linguistic processing" (page 394). Chu-chang and Loritz (1977) proposed a two-stage model of reading proficiency, suggesting that at earlier stages of learning to read, STM representation of written material is primarily visual, while at more developed stages STM for written material becomes primarily phonological. On the other hand, Tzeng and his colleagues (1977) cautioned against exaggerated interpretations of cross-orthographic data supporting theories of phonological recoding in reading, pointing out that phonological recoding may be just one of several strategies readers may use to access the meaning of a linguistic symbol and that other factors such as difficulty of material and reader purpose may effect a reader's reliance on phonemic recoding. Yet, at the same time, Tzeng and his colleagues also suggest that the data from experiments may indicate similarity rather than difference in the visual processing of Chinese characters and English words and that "both processes involve phonetic recoding of visually presented symbols" (page 626).

In additional to the studies mentioned above, a more recent study by Zhang and Simon (1985) supports the role of phonetic recoding in working memory. In a series designed to reconcile two competing hypotheses about the capacity of STM, Zhang and Simon used homophonic and non-homophonic Chinese radicals and characters to test STM span. Their results showed both that Chinese readers made a substantial number of homophone errors in recall of stimuli (that is, their memory of logographic stimuli was phonetically correct but graphemically incorrect) and that the STM span for unnamed radicals and homophonic characters was about half of that for characters and radicals with distinct names. Their conclusion, similar to those of the authors mentioned above, is that STM utilizes both acoustic and non-acoustic encodings. Zhang and Simon (1985) remark: "These results with Chinese language materials are especially interesting because it has often been claimed that Chinese readers, unlike readers of alphabetic languages, encode the ideographic characters directly from visual to semantic without going through an intermediary acoustic encoding. The high rate of homophonic intrusion in Experiment 1 and the low measured span of nonacoustic STM make this claim dubious. It would appear that the oral language is an essential intermediary in the extraction of meaning from both kinds of texts." In light of the research that had already been done concerning the issue of speech recoding in the reading of Chinese characters, the lack of citations of these works by Biederman and Tsao underscores the complexity of research into psycholinguistic aspects of reading processes and the need for active collaboration between authors among divergent, yet critically overlapping, fields of inquiry.

In all, it seems clear that Biederman and Tsao did not adequately address a number of important variables that undermine both their findings and their ideas about the "widespread implications" of their data. On the other hand, other studies[5] support Biederman and Tsao's notion that there are some differences on some level between readers' abilities to perceive visual and verbal information. Perhaps the best way to reconcile the disparate mixture of data indicated by these studies is to investigate more vigorously the possible models for how meaning of written information might be mediated through a combination of visual and acoustical routes. At the same time, it is unfortunate that more cross-orthographic Stroop research has not emphasized the quest for the locus of Stroop interference, for such evidence could address the question of whether the differences in Stroop effects shown by readers of logographic and alphabetic orthographies are due to fundamental differences in human information processing mechanisms or to differences in the learned patterns of attention to features of language by readers. If the latter is indeed the case, it could in turn lead to further work, initially to capture and describe how first language perception and production might affect the learning of reading and writing skills in second languages, and then to develop teaching methods that incorporate an understanding of those differences in the teaching of second languages, particularly when the languages are represented by different orthographies. Whatever the goal of the research across languages and cultures, however, rival hypotheses in studies such as those reviewed here emphasize the necessity for investigators to consider the social and cultural factors that lie on the trail to understanding language and cognition.

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Endnotes

1 If this paper has been duplicated, the two examples above that should be printed in red ink, the first "BLUE" and the square color patch, may not have been duplicated in color.

2 Written Japanese is increasingly incorporating alphabetic symbols in daily use, but far from the extent that it is a necessity for literacy. For more information on this topic, see Saint-Jacques, 1987.

3 For evidence of this, Biederman and Tsao primarily cite studies of Japanese aphasics, e.g., Sasanuma, 1975, 1977.

4 This argument is also made by Unger (1987) in his text exploring relationships between artificial intelligence, the Japanese writing system and the development of computer technologies. Readers should also note that stroke count is only one way of "measuring" the visual complexity of these kinds of logographic characters. The frequency of part or the whole of the character, for example, may also effect visual recognition time.

5 For example, see Paradis, Hagiwara and Hildebrandt's text (1985) on neurolinguistic aspects of the Japanese writing system.

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