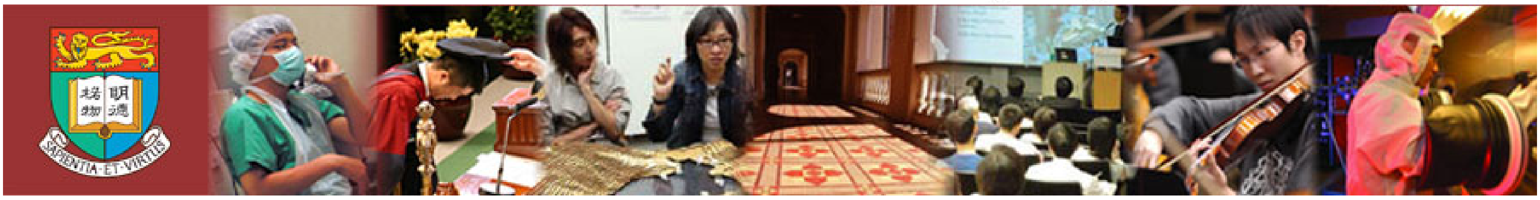

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Semantic categorization of Chinese character:

semantic radical plays an important role?

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Abstract

Most Chinese characters are composed of a semantic radical and a phonetic radical. Phonetic radical has been found to play a significant role in reading but the role of semantic radical was not clear. This study used a semantic categorization task to investigate whether semantic radical plays an important role in learning Chinese characters. Grade 1, 3 and 5 children had to choose among four pictures of ‘target’, ‘phonetic radical distractor’, ‘semantic radical distractor’ and ‘unrelated distractor’ that best matched meaning of the written character. Results indicated that semantic radical did not play a significant role in understanding and learning characters. Children prefer using the phonetic radical in the reading process. Further analysis supported the alternative hypothesis: the phonetic radical plays in important role in understanding meaning. Most errors fell into the category of phonetic radical distractor and an effect of phonetic regularity on performance was observed. A framework about sublexical processing of Chinese characters in semantic categorization task was proposed to explain the findings.

Introduction

Introduction to Chinese orthography

Over 80% Chinese characters are semantic-phonetic compounds (Chen, 1996)**.** Each of them is composed of phonetic radical which gives hint to the pronunciation of the character and a semantic radical which gives hint to the meaning of the character. Take the character ‘椰’ /j↔4/ (coconut) as an example. The phonetic radical ‘耶’ /j↔4/ gives clue to pronunciation and the semantic radical ‘木’ (plant, wood) gives clue to meaning.

The information conveyed by the semantic radical and phonetic radical is not always reliable. The concepts of regularity and consistency have been used to describe the reliability of the information carried by radicals of a semantic-phonetic compound. Phonologically, characters can be divided into three categories based on the relationship between the character’s pronunciation and that of the phonetic radicals. Regular characters have identical pronunciation with the phonetic radical while irregular characters has completely different one. Semi-regular characters lie between regular and irregular characters (Table 1). Semantically, the characters ‘椰’ [coconut]) has a meaning directly related to the meaning of its semantic radical ‘木’ [plant]) is categorized as transparent characters. The meaning of semi-transparent characters (e.g. ‘枯’ [decay]) is only indirectly related to the semantic radical (e.g. ‘木’ [plant]). Opaque characters (e.g. ‘權’ [authority]) have meanings completely unrelated to the semantic radical (e.g. ‘木’ [plant]).

Table 1 Examples of regular, semi-regular and irregular characters

Category	Character	Phonetic radical
Regular	椰 /j↔4/ (Coconut)	耶 /j↔4/
Semi-regular	松 /tsu|4/ (Pine tree)	公/ku|1/
Irregular	桃 /tou4/ (Peach)	兆 /siu6/

Characters sharing the same phonetic radical (e.g. 借, 醋, 措, 錯, 惜) or semantic radical (椰, 松, 桃, 枯, 櫂) are in the same phonetic or semantic family. A phonetic radical is more consistent if characters containing it shares similar pronunciation. A semantic radical is considered more consistent if it coveys similar meanings in the family. The semantic radical ‘鳥’ (bird) consistently conveys the meaning ‘bird’ in all the characters carry it (e.g. ‘鵝’ [goose], ‘鴨’ [duck], ‘鴉’ [crow], ‘鴿’ [pigeon]) and its semantic consistency is high. The semantic radical ‘大’ (big) coveys divergent meanings in its family (e.g. ‘獎’ [prize], ‘奢’ [luxurious], ‘契’ [contract], ‘奕’ [in sequence, abundant]) and its semantic consistency is low. The semantic radical has higher semantic consistency when its family contains more transparent characters because their meanings are related to the semantic radical (Chen & Weekes, in press) (Table 2).

Table 2 *Examples of consistent and inconsistent phonetic radical*

Type	Phonetic radical	Family
Consistent	盧 /lou4/	廬 /lou4/ , 爐 /lou4/, 驢 /lou4/, 蘆/lou4/ , 顱/lou4/
Inconsistent	聿 /w□t6/	律 / leot6/, 肆 / si3/, 津 / zeon1/

It has been established that children and adults decompose the semantic and phonetic radicals in processing of Chinese characters, i.e. the *sublexical processing* in Chinese (Taft & Zhu, 1997). Extensive research had demonstrated better performance in regular characters than semi-regular and irregular characters in character naming and lexicon decision tasks. Characters with higher phonetic consistency were also found to be read better than that ones with lower consistency (Shu, Zhou, & Wu, 2000; Yang & Peng, 1997). It has been concluded that the phonetic radical plays an important role in reading aloud. There were only a few studies investigating the role of semantic radical in understanding meaning with equivocal results.

If the semantic radical is important for reading and learning characters, transparent characters would be read better than opaque characters. The semantic radical can be used to activate the understanding of transparent characters but not opaque characters. Characters with higher semantic consistency would be expected to have better performance than those with lower consistency. A less consistent semantic radical would activate divergent meanings. The competition among the divergent meanings may cause greater difficulties in understanding a character (Chen & Weekes, in press).

Shu & Anderson (1997) has studied the effect of semantic transparency in a pinyin task. A two-character word is presented but the first character is given as pinyin (e.g. tong 孔 [pupil of the eyes]). Children were asked to choose among 4 characters with the same semantic radial (e.g. 瞳[pupil of the eyes], 撞[collide], 僮[boy servant], 潼 [lofty, damp]) to replace the pinyin in the first character. Their study found that fist, third and fifth graders performed better in semantically transparent characters than in opaque characters. The study held the phonetic radical (e.g. 童 [child]) constant but varied the semantic radicals (e.g. 目, 扌, 亻, 氵) in each question. Shu's study was inadequate in understanding the role of semantic radical. It did not test reading in a real life situation where children are free to make use of the phonetic or semantic radical. The effect of semantic transparency across different semantic consistency conditions was not examined.

Kwan (2003) and Chen and Weekes (in press) attempted to study the role of the semantic radical in real life situation. They employed a semantic categorization task to study the effect of semantic transparency in school-aged children and adults respectively. Binary choice paradigm was used, subjects had to answer 'Yes' when the presented target belongs to the presented category and ‘No’ when it was not. The answer for a transparent character was ‘Yes’ and that for an opaque character is ‘No’. Both of them found the results of significantly better performance in opaque than transparent characters. Kwan (2003) pointed out, the ‘No’ response came from two sources. Subjects might tend to be conservative and answered ‘No’ whey they are not sure. The better performance in opaque might be an artifact of the binary choice paradigm. Alternatively, opaque characters are easier to be memorized for some unknown reasons. While the effect of semantic consistency on reading by children was not addressed by Kwan’s (2003) study, both studies failed to draw a conclusion about the importance of the semantic radical.

Chen (2001) was the only study that investigated semantic consistency (she used the term ‘*transparency*’ in her study) in children. Normal and dyslexic fourth graders were asked to select one answer from four characters that best matches the meaning of the target (e.g. 疾 [disease]). Two characters shared the same phonetic radical (e.g. 嫉 [jealous]) and the semantic radical (e.g. 病 [sick]) with the target and other choices were unrelated to the target (e.g.度 [degree, consider], 廚 [kitchen]). The stimuli included real and pseudocharacters. The real characters were selected from textbooks of Grade 1 and 4. Performance in characters with high semantic consistency was significantly better than that of low consistency. The results of the study should be interpreted with caution. The frequency level of the stimuli was not controlled and this might confound the results. The children were given choices sharing the same phonetic or semantic radial with the target and this may bias them in analyzing internal character structure and this did not reflect reading in real life situation. The effect of semantic consistency across different semantic transparency conditions was not investigated.

The present study aim at asking three research questions. Two were related to what were not adequately addressed by previous studies because of methodological limitation: does the semantic radical play an important role in understanding and learning Chinese character in real life? What is the interaction between semantic transparency and consistency? The third research question is the role of the semantic radical across reading development. Information about reading development has implications in education of normal children and understanding of dyslexia. Learners of alphabetical languages were found to learn word by word based on visual features in the logographic stage. They gradually master rules of the language system and use ‘cipher’, i.e. phonetic regularity, to memorize words in the alphabetical stage. Advanced readers process characters as whole in the orthographic stage. Reading development in Chinese is less clear. Semantic radical awareness seemed to be more consolidated from the third grade, when children were found to use the semantic radical to understanding meaning (Ho, Ng, & Ng, 2003) First, third and fifth graders would be studied to trace the reading strategies of beginner, intermediate and advanced readers.

Methodological considerations

Semantic categorization task would be used to alleviate the methodological problem of previous studies because it can tap processing of meaning without biasing children towards analyzing phonetic and semantic radicals.. Pseudocharacters were not used and the phonetic radical were not kept constant to reflect reading in real life situation. Multiple choice tests were used to avoid the scoring bias brought by binary choice test. Instead four choices: target, phonetic radical distractor, semantic radical distractor and unrelated distractor were provided. Error analysis on the pattern of choices made by children might provide more information of how a child processes an incoming character and what role does the semantic radical play in the process. Extraneous variables including strokes, family size, semantic radical frequency would be controlled. (Refer to the ‘Method’ section for details.)

Prediction of Results

If the semantic radical plays a significant role in reading Chinese character, performance in transparent characters would be better than that in opaque characters. Performance in characters with higher semantic consistency would better than that with low consistency. Alternatively, the semantic radical may be neither necessary nor sufficient in activating meaning. When a character (e.g. 餵 [feed]) is read, multiple activations interact. These include activations at radical level, i.e. semantic radical. (飠 [eat]) and phonetic radical (畏 /w□i/), at character level (餵 [feed]) and at word level (e.g. 餵奶 [feed milk]). Semantic transparency and consistency effect is not a must. Error pattern analysis will be conducted to supplement information about children’s learning strategies. The ratio of errors falling into phonetic or semantic radical distractors may shed a light on revealing children’s preference in using the phonetic or semantic radical. If the major error type is unrelated distractor, it may indicate that children do not analyze internal structure of characters in their learning.

Method

Subjects

Ninety-eight subjects from four local primary schools: 30 first graders, 38 third graders and 30 fifth graders were selected as subjects. They completed the Raven's Standard Progressive Matrices (SPM) (Raven, 1986), a standardized non-verbal intelligence test and the Chinese Word Reading sub-test of The Hong Kong Test of Specific Learning Difficulties in Reading and Writing (Ho, Chan and Education Department, 2000).The subjects had normal intelligence (90 or above in SPM) and reading ability (-1.33 or above in reading test). All subjects were native Cantonese speakers and had normal or corrected-to-normal vision. One-way ANOVA showed that the standard scores of SPM [$F(2, 95) = 2.15$, $p = 0.1255$] and reading test [$F(2, 95) = 2.73$, $p = 0.07$] of the three grades were not significantly different from each other. Age ranges and performances of subjects on the two screening tests were summarized in Table 3.

Table 3 *Age, non-verbal intelligence and reading ability of the subjects*

Grade	Age range	Raven's Standard Progressive Matrices	Chinese word reading sub-test
		Mean Standard Score *(SD)*	Mean Scaled Score *(SD)*
Grade 1	6;03 -7;04	111.00 (11.53)	10.13 (3.00)
Grade 3	8;02- 9;11	114.50 (11.52)	11.13 (2.22)
Grade 5	10;4- 11;0	111.70 (10.95)	11.70 (2.32)

Design & Materials

Three sets of 80 target characters were prepared, each set for each grade. The characters were divided into eight categories according to character frequency (high, low), semantic consistency (high, low) and transparency (transparent, opaque) (Table 4).

Table 4 Categories of stimuli for each grade

Character Frequency	Semantic consistency	Transparency	
		Transparent	Opaque
High	High	HcTHs	HcOHs
	Low	HcTLs	HcOLs
Low	High	LcTHs	LcOHs
	Low	LcTLs	LcOLs

The stimuli were traditional Chinese characters chosen from the Hong Kong Corpus of Primary School Chinese (Leung & Lee, 2002) which was input from primary school Chinese and General studies textbooks. The corpus reflects the frequency of characters the children encounter more objectively.

Calculation of Character Frequency

A cumulative frequency for each character was calculated for each grade. For example, the cumulative frequency of the character '線' (thread) at Grade 3 is computed by summing up its frequency in Grade 1 (36), Grade 2 (24) and Grade 3(79), equal to 149. The cumulative frequencies of all characters are ranked by ascending order. The characters at the two extremes were selected as high and low frequency characters.

Rating of Semantic Transparency

Semantic transparency values of characters were rated by five undergraduates in the University of Hong Kong. They were born in Hong Kong and native speakers of Cantonese. They rated transparency value of each character from 1 to 6 independently. Operational definitions of the value 1 to 6 were given before rating started. The system was based on Kwan (2003)'s study. The operational definitions of rating 1 to 5 are listed in Appendix I. All raters agreed on the definition of semantic radicals (e.g. 氵 stands for water) before the rating procedures starts. If the meaning of the semantic radical is ambiguous, the transparency values of the family would not be rated. Each rater independently rated the transparency value of all characters first. If the majority (three or more people) gave the identical rating for a character, the rating will be adopted. Otherwise, the five judges will discuss the appropriate rating of the character. The procedure was to ensure a common ground on the meaning of the character, the semantic radical and the definition of semantic transparency.

Calculation of semantic consistency

The calculation of semantic consistency was based on Chen (2002)'s formula:

$$\text{Semantic consistency} = \frac{1 \times T + 0.5 \times S}{\text{Family size}}$$

Note. T = Number of transparent characters S = Number of semi-transparent characters

A semantic consistency index was computed for each semantic radical in each grade. For example, the semantic radical '雨' made up 4 characters in Grade 1: 2 characters were transparent, 1 character was semi-transparent and 1 character was opaque. The semantic consistency of the radical is 0.625 [(1 × 2 + 0.5 × 1) / 4]. The more transparent characters a semantic radical contained, the more consistent was the semantic radical. The radicals at the two extremes were selected as radicals of high or low consistency.

Control of extraneous variables

The number of strokes was balanced for each category. Due to the distribution of characters in Chinese (Leung & Lee, 2002; Shu, Chen, Anderson, Wu & Xuan, 2003), the phonetic regularity of characters, family size (number of characters containing the same radical), semantic radical frequency[1] and the number of semantic radical which can standalone as a character[2] in each category could not be balanced. At the best effort of the author, the properties of transparent and opaque characters under the same conditions (e.g. low character frequency, low semantic consistency) could be balanced in most cases (Appendix I).

Choice of distractors for the multiple choice test

For each item, subjects had to choose a picture from four choices that best matches the meaning of the character. The four choices were correct answer, phonetic radical distractor, semantic radical distractor. Table 5 shows the examples of foils for a transparent and opaque character. The choices were presented in pictures to alleviate bias in drawing children's attention to the radicals. Because of the properties of Chinese characters, it was impossible to control the properties of the distractors.

Table 5 Examples of foils for a transparent and opaque character

Type of character	Target	Correct answer	Phonetic radical distractor	Semantic radical distractor	Unrelated distractor
Transparent	稻 (Grain)	禾 (Grain)	蹈 (Foot and its action)	秤 (Steelyard)	車 (Cars)
Opaque	稚 (young)	稚 (young)	堆 (accumulate)	禾 (Grain)	紐 (Button)

[2] Semantic radical frequency refers to the total frequency of characters containing the radical in the grade. For example, the semantic radical frequency of the radical '欠' at Grade 1is calculated by summing up frequency of characters in the family, i.e. '歡' (46), '次' (8), '欣' (3) and '次' (1), which is equal to 58.

[3] Some semantic radicals can standalone as a character (e.g. 木, 口, 欠) but some only form part of character (e.g. 氵, , 糹).

Stimuli

Stimuli of each grade were printed in a booklet of A4 size. Each page printed a target word using ‘biau kai’ (標楷體) font, sized 36. Four line drawings are printed in the size of 10 cm ✕ 7cm, with the label of ‘A’, ‘B’, ‘C’ or ‘D’. To avoid distraction, the stimuli were printed one-sided. The back page of each item was printed with intense black dots so that subjects could not see the following page. Answer sheets of A4 size were provided. Each page printed 5 items. Each item printed the question number and boxes labeled with ‘A’, ‘B’, ‘C’ and ‘D’. The order of boxes was the same as that in the booklet to avoid marking error (Appendix III).

Procedures

The test was administered in the form of a paper-and-pen test. Subjects had to decide which picture best represented the semantic category of the character. They put a tick to the corresponding box in the answer sheet. The chief examiner explained the procedures of the test and run 8 practice trials to familiarize the subjects with the task. The other examiners ensured that the children understand the task and gave clearer instructions if necessary. The subjects had to finish the test within 1 hour 15 minutes.

Measurement

One mark was given to correct answer and no mark was given to wrong answer.

Data Analysis

A 3 (grade) ✕ 2 (semantic transparency) ✕ 2 (character frequency) ✕ 2 (semantic consistency) four-way ANOVA with repeated measure was carried out. Character frequency (two levels: high and low), semantic transparency (two levels: transparent and opaque), and semantic consistency (two levels: high and low) were within-subject variables and grade (three levels: Grade 1, Grade 3 and Grade 5) were between-subject variables.

Results

The means and standard deviations of the subjects' overall performance in different conditions are reported in Table 6.

Table 6 Mean Percentage Scores of the Subjects' Overall Performance

Grade	Overall percentage score (%)	Mean percentage score in different conditions (%)					
	Mean (*SD*)			Character frequency and semantic consistency			
				Hc, Hs	*Hc, Ls*	*Lc, Hs*	*Lc, Ls*
Grade 1	56.1 (10.83)	Transparency	*T*	63.7	64.0	38.0	40.7
			O	74.3	67.7	43.7	57.3
Grade 3	74.5 (6.72)	Transparency	*T*	84.5	84.7	57.1	76.3
			O	83.2	91.8	62.9	55.8
Grade 5	80.9 (4.40)	Transparency	*T*	92.0	89.7	73.7	57.3
			O	92.7	97.3	71.7	73.3

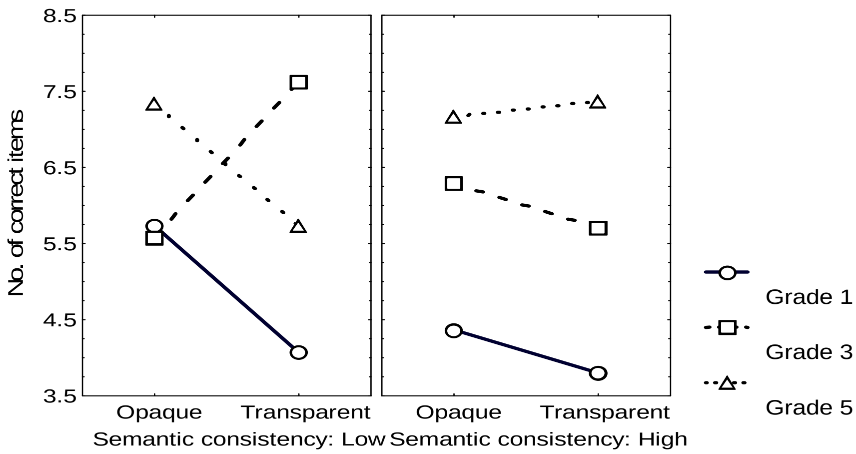
A four-way ANOVA with repeated measures was performed. The main effect of grade was significant, F (2, 95) = 54.21; p<.001. Fifth graders performed better than third graders (Tukey HDS test, p< .001); third graders better than first graders (Tukey HDS test, p< .020).

The main effect of frequency was significant, F (1, 95) = 2565.63; p<.001.High frequency characters read better than low frequency characters (Tukey HDS test, p< .001).

The main effect of transparency was significant, F (1, 95) = 11.60; p<.001. Opaque characters were read better than transparent characters (Tukey HDS test, p< .001).

The interaction between grade, frequency, transparency and semantic consistency was significant, F (2, 95) = 19.60; p<.001. There was no significant difference between the different transparency and semantic consistency conditions in the high character frequency condition. Significant transparency effect were found in the low frequency and low semantic consistency condition only, with better performance in opaque characters in Grade 1 (p<.001) and Grade 5 (p<.003) and better performance in transparent characters (p<.0001) in Grade 5.

Figure 1 Interaction between Semantic Transparency and Consistency in Low



Characters with high semantic consistency were read better than that with low semantic consistency in the low character frequency and transparent condition (Tukey HDS, p<.002).

Error pattern analysis was done. The percentage of errors falling into different types of distractors was computed for each grade. Most errors fell into the category of phonetic radical distractor in all grades (Table 7).

Table 7 *Average % of errors in different types of distractors across the grades*

Grade	PD (%)	SD (%)	UD (%)
1	**48.72%**	31.20%	18.24%
3	**56.76%**	30.36%	12.97%
5	**68.92%**	16.33%	13.05%

Note: PD – Phonetic radical distrator, SD – Semantic radical distractor, UD – Unrelated distractor

Discussion

Because the frequency of stimuli for was controlled for each grade, the main effect of grade was unlikely to be caused by the lack of control of stimuli, leading to higher grade having more exposure to the stimuli. The grade effect may be explained by more mature skills of learning Chinese characters with increased exposure of reading. Children develop metalinguistic awareness in reading development. They gradually master the skills of analyzing internal character structure to understand characters (Li, Anderson, Nagy & Zhang, 2002; Shu & Anderson, 1999).

Consistent with the study of Li & Chen (1999), the effect of semantic radical was not found for high frequency characters. Children may map a familiar character directly with meaning without decomposing radicals. The focus of this study is the role of semantic radical in sublexcial processing and the processing on whole character basis would not be explored here.

Children generally perform better in opaque than transparent characters. This result was generally consistent with Kwan (2003) and Chen et al. (in press)'s findings of better performance in opaque characters. The fact that a negative transparency effect was found in the present experiment after eliminating the possible methodological bias of binary choice and controlling extraneous variables appeared to support that negative transparency effect is a fact but not an artifact of methodological problems.

Fifth graders performed significantly better in consistent than inconsistent characters in low frequency and transparent condition. Divergent meanings were activated for an inconsistent radical and the competition of meanings might lead to more errors in judgment. The consistency effect was only found in fifth graders but not younger readers can be explained by more reading experience and the types of characters they encounter. The fifth graders know the greatest number of characters and range of meanings in each semantic family. They are exposed to more opaque characters than transparent ones, opposite to the ratio of characters first and third graders encounter (Table 8). The competition of meanings would be most significant in fifth graders in an inconsistent radical.

Table 8 *Distribution of transparent and opaque characters across three grades*

	Grade 1	Grade 3	Grade 5
Transparent	289	658	992
Opaque	258	483	1403

The consistency effect was only found in transparent condition. The competition of divergent meanings would lead to less chance of choosing the meaning of the semantic radical (e.g. 禾 [grain]). One of the meanings in the family (e.g. 稚 [young], 穢 [dirty], 積 [accumulate], 稀 [rare] 秤 [steelyard]) may be chosen. This must lead to more errors in transparent character (e.g. 稻 [grain]) but not necessarily in an opaque character (e.g.稚 [young]). Low semantic consistency did not bring the disadvantage to an opaque character as that to a transparent character.

Investigating the processing strategies of children: error analysis and interview

The direction of semantic transparency effect was different across grades. The transparency effect of all grades occurred in low frequency and low semantic consistency conditions. First and fifth graders performed better in opaque than transparent characters. Third graders performed better in transparent than opaque characters. The processing strategies of the subjects were investigated by error analysis and a interview of primary school children.

According to the error analysis, most errors fell into the category of phonetic radical distractor. Children tended to use phonetic radicals as a clue to meaning and chose the character sharing the same phonetic radical with the target.

The effect of phonetic regularity on performance was also investigated. In all grades, regular characters had lowest accuracy; semi-regular characters obtained higher accuracy and irregular characters obtained highest accuracy (Table 9).

Table 9 *Performance of subjects in regular, semi-regular, irregular characters*

	Regular	Semi-regular	Irregular
Grade 1	12.33	16.29	20.3
Grade 3	23.27	27.37	34.44
Grade 5	23.88	24.48	27.11

The effect of phonetic regularity on performance might suggest a robust effect of the phonetic radical. The semantic transparency and semantic consistency of characters across different regularity conditions varied but these semantic properties did not overshadow the effect of regularity. Evidence from error pattern analysis and effect of phonetic regularity appeared to show a stronger preference to use the phonetic radical in processing.

To have an idea about how children understand process a character, we interviewed 12 students of Grade 1, 3 and 5 (four each). All students reported that they would name the phonetic radical or use phonetic analogy for unfamiliar characters. Third and Fifth graders would not choose phonetic radical distractors when they are too common or rare. The reason they gave was that if the phonetic radical distractor was common, they would have known that its orthographic representation is different from that of the target; for rare phonetic radical, they did not choose simply because they know nothing about it distractors. Fifth graders would not choose the meaning of semantic radical when they think it is inconsistent. These radicals conveyed a wide range of meanings and it was difficult to judge which meaning was conveyed in a particular character.

Further analysis was carried out to see if the interview represents the view of most subjects. The results provided preliminary support for students' claims. Our findings about the influence of phonetic radical on accuracy, that is,. the phonetic radical distractor as the most frequent error type and the effect of regularity on accuracy, supported the students' claims that they read aloud characters in the process. The students' claim of not choosing phonetic radical distractor that are too common (high frequency and rare (low frequency) was supported by evidence.In Grade 3 and 5, most items with high percentage in phonetic radical distractors had phonetic radical distractors of medium frequency. The positive consistency effect found in Grade 5 supported fifth graders' claim about their making choices based on semantic consistency.

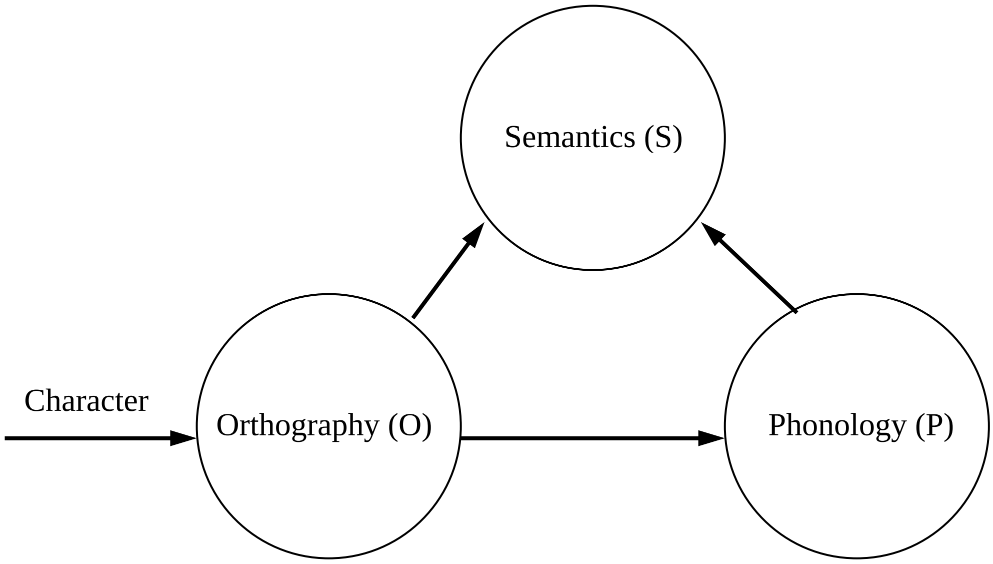
Table 10 *Distribution of frequency levels of phonetic radical distractors in items with over 40 % subjects making phonetic errors*

	High Frequency	Medium Frequency	Low Frequency
Grade 1	16	14	15
Grade 3	9	14	8
Grade 5	10	17	5

Routes and sub-skills of processing across grades

The triangular model with Orthography (O), Phonology (P) and Semantics (S) has been widely used to explain processing of characters and words (e.g. Pefetti & Tan, 1998) (Diagram 1).

Diagram 1 *Schematic representation of the lexical processing system*



Using 趾 /tsi2/ [toe] as an example, children firstly break down the character into radicals and identify the semantic radical (e.g.⻊ [foot]) and phonetic radical (e.g. 止 /tsi2/) from a character. They can follow the Orthography (O) → Phonology (P) → Semantics (S) route after decomposing the phonetic radical. By naming the phonetic radical (e.g. 止 /tsi2/) or using the phonetic analogy (e.g. 扯 /ts^h↔/ [pull], 址/zi2/ [address],) they can generate the pronunciation of the phonetic radical distractor (e.g. /ts^h↔/). The pronunciation of the target (e.g. /tsi2/) may be correctly estimated if the character is a regular character, i.e. sharing the same pronunciation as the phonetic radical (Route: O → P). Children then map the pronunciation(s) (e.g. /zi2/, /ts^h↔/) with meaning (Route: P → S). The O → P → S route would generate the meaning of the phonetic radical distractor (e.g. 扯 /ts^h↔/ [pull]) for all characters. The meaning of the target (e.g. 趾 /tsi2/ [toe]) may be also generated. First graders were found to demonstrate the skill of using phonetic radical as a clue to pronunciation. (Chan and Siegel, 2001; Ho, Ng & Ng, 2003). Before literacy development, children have already developed a strong link between phonology and semantics in spoken language. It is reasonable to suggest that children of Grade 1, 3, and 5 was able to use to O → P → S route. By using the O → P → S, when a regular character is read aloud, both the target and the phonetic radical distractor would be generated. Would children choose the target or the phonetic radical distractor? The data seemed to suggest that children tended to choose the phonetic radical distactor for regular characters. The regular characters had lowest accuracy in each grade, comparing with semi-regular and irregular characters.

By following the Orthography (O) → Semantics (S) route in sublexical processing, children have to understand the meaning of semantic radical. This route would generate target for a transparent character and semantic radical distractor for an opaque character. When the meaning of the semantic radical '⻊' [foot]) is activated, children would choose the category of 'foot and toes'. They would choose the target in the transparent character '趾' (toe) but choose the semantic radical distractor in the opaque character '躁' (excited, irritable). The ability to use semantic radical as a clue to meaning was found to emerge later than using phonetic radical to read aloud, earliest at Grade 3 (Cheng and Huang, 1995; Ho, Ng & Ng, 2003; Shu and Anderson, 1997). It seemed that children of Grade 3 and 5 able to use the O → S route.

There are other sub-skills in deciding the answer when the route(s) can generate more than one answer. Children may retrieve the orthographic representation of the pronunciation (e.g. 扯 /ts^{h}↔/ [pull]) generated and compare with the written stimuli (e.g. 趾 /tsi2/ [toe]) in the box of Orthography (O). They may not choose the answer if the easily retrieved representation is different from the target (in high frequency characters) or they cannot retrieve the representation (in low frequency characters). This sub-skill was found in third and fifth graders evidenced by the interview and data that they would only tend to choose phonetic radical distractors when they are at medium frequency. Children also have to decide the usefulness of information provided by the semantic radical in the box of Semantics (S). They may not choose the semantic radical when was inconsistent. Evidence only showed that fifth graders had this concept of semantic consistency. Table 11 summarized the strategies of different grades.

Table 11 *Routes and Sub-skills used by Children of Different Grade*

Grade	*Route(s)*	*Other sub-skill(s)*
1	O → P → S	Nil
3	O → P → S and O → S	Retrieve the orthographic representation of the phonetic radical distractor
5	O → P → S and O → S	(1) Retrieve the orthographic representation of the phonetic radical distractor (2) Decide the consistency of meaning conveyed by semantic radical

Explaining the data

The implementations of routes and strategies by children of different grades could be used to explain the transparency effect. Grade 1 children used the O → P → S route and this would generate the target and phonetic radical distractor. The accuracy depends on whether children choose the target or phonetic radical distractor when they have two options. According to the observation, children tended to choose the phonetic radical distactor for regular characters. Transparent characters were more regular than opaque in Grade 1, especially in the low semantic consistency condition (Table 12). In low semantic consistency condition, children chose more targets in the opaque category and more phonetic radical distractors in transparent characters, leading to better performance in opaque characters.

Table 12 *Distribution of regular, semi-regular and irregular characters in Grade One*

	LcTLs	LcOLs	LcTHs	LcOHs	HcTLs	HcOLs	HcTHs	HcOHs
Regular	3	0	1	0	1	0	1	0
Semi-regular	2	8	6	7	7	4	5	6
Irregular	0	2	1	1	0	4	1	1

Grade 3 children use O → P → S and O → S routes. The O → S route can generate the target for a transparent character and the semantic radical distractor for a opaque character. By using both routes, transparent characters had an advantage. The target of opaque can be generated by one route only but that of transparent by two routes. This may lead to better performance in the low semantic consistency condition. Transparent characters in high semantic consistency condition tended to have more regular characters (Table 13) and phonetic radical distractors of medium frequency (Table 14). This may lead to more choices towards the phonetic radical distractors and off-set the advantage brought by the O → S route.

Table 13 Distribution of regular, semi-regular and irregular characters in Grade 3

	LcTLs	LcTHs	LcOHs	LcOLs	HcTLs	HcOLs	HcTHs	HcOHs
Regular	1	3	3	1	1	0	1	1
Semi-regular	5	5	5	6	5	6	4	7
Irregular	2	1	0	2	3	0	1	0

Table 14 Frequency levels of phonetic radical distractors for low frequency transparent characters in Grade 3

	Low semantic consistency	High semantic consistency
High Frequency	1	1
Medium Frequency	5	7
Low Frequency	4	2

Grade 5 children would not utilize the semantic radical if it was inconsistent. They may not use the O → S route in low semantic consistency condition. They chose between the target and the phonetic radical distractor generated by the O → P → S route. Children tended to choose the phonetic radical distractor for regular characters. Because transparent characters of Grade 5 were more regular (Table 15), performance of opaque character would be better.

Table 15 *Distribution of regular, semi-regular and irregular characters in Grade 3*

	LcTLs	LcOLs	LcTHs	LcOHs	HcTLs	HcOLs	HcTHs	HcOHs
Regular	4	1	5	1	2	1	2	1
Semi-regular	5	6	4	6	4	3	5	8
Irregular	0	1	0	1	2	4	0	1

Testing the strong phonology hypothesis in previous studies

Kwan (2003) and Chen & Weekes (in press) found better performance in opaque characters than transparent characters in low frequency conditions and all conditions respectively. To test the proposed hypothesis of strong phonology effect in semantic activation, the phonetic regularity of stimuli of Kwan (2003)'s study in low frequency condition and Chen & Weekes (in press)'s study were analyzed. The analysis was conducted according to the pronunciation of characters and phonetic radicals of corresponding dialects, i.e. Cantonese in Kwan (2003) and Putonghua in Chen & Weekes (in press). The transparent characters tended to be more regular than the opaque characters (Table 16 and 17). These results provided preliminary support for the idea that the phonetic radical is preferred in reading Chinese characters.

Table 16 Distribution of types of low frequency character in Kwan (2003)'s study

Grade	Regular		Semi-reg		Irregular	
	Trans	*Opaque*	*Trans*	*Opaque*	*Trans*	*Opaque*
2	5	33	9	7	4	3
3	6	4	6	9	2	4
4	5	6	8	9	0	2

Note. Trans –Transparent, Semi-reg – Semi-regular

Table 17 Distribution of types of character in Chen & Weekes (in press)'s study

	Transparent	Opaque
Regular	28	8
Semi-regular	57	54
Irregular	17	14

Theoretical implications

Intuition may lead us to expect that the semantic radical plays an important role of in reading and learning Chinese characters. Evidence from two previous studies (Chen & Weekes, in press; Kwan, 2003) and from the current study was inconsistent with this expectation. The importance oof the semantic radical in Chinese reading may have to be re-considered. According to the above analysis, it appears that although semantic radical does play a role in reading and learning, children may have a preference for using the phonetic radical.

The number of different semantic radicals in each grade is less than that of phonetic radicals (Table 18). There would be more semantic-phonetic compounds composed of the same semantic radical than of the same phonetic radical. The frequency of exposure of the semantic radicals would be higher than that of the phonetic radical. It was generally agreed that materials with more exposure would facilitate processing more in psycholinguistic studies, i.e. frequency effect (Ellis & Young, 1988). Result of this study was inconsistent with this view; children prefer using the phonetic radical which has lower frequency of exposure. Therefore, the preference in using the phonetic radical could not be explained by frequency effect.

Table 18 *Number of different semantic and phonetic radicals in Grade 1, 3 and 5*

Grade	No. of semantic-phonetic compounds	No. of different semantic radical	No. of different phonetic radical
1	831	117	513
3	1714	139	838
5	2493	155	1046

Whether phonology plays an important role in semantic activation has attracted much attention in current research of Chinese reading. Although phonological activation was found automatic and faster and than that of semantic activation (e.g. Perfetti & Zhang, 1995; Zhou & Marslen-Wilson, 2000) and the meaning of phonetic radical is automatically activated (Zhou & Marslen Wilson, 2002), contradictory results were found regarding the relative importance of the O → P → S or the O → S route (e.g. Chen & Shu, 1997; Perfetti & Tan, 1998; Zhou & Marslen Wilson, 1999). Evidence from Kwan (2003) and Chen & Weekes (in press) and from the current study seemed to support the strong phonological view in reading Chinese; the O → P → S route appears to be preferred to the O → S route in processing.

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Appendix I *Operational definitions of rating for semantic transparency*

Rating	Definition	Example	
		Semantic radical	**Character**
1	The meaning of the semantic radical and the character is the same.	目 (eye)	眼 (eye)
2	The character belongs to the category of the semantic radical.	女 (female)	姐 (elder sister)
3	The meaning of the character is directly related to the semantic radical. For example, the semantic radical (木[wood]) is the raw materials of the character (櫃[wardrobe])	木 (wood)	櫃 (wardrobe)
4	The meaning of the character is indirectly related to radical. For example, '火' (fire) is a by-product of burning and is indirectly related with its semantic radical '煙'. (smoke)	火 (fire)	煙 (smoke)
5	The meaning of character is only loosely related to radical. For instance, the character '漆' (oil paint) is not made from water but both '漆' and its semantic radical 氵 (water) are liquid.	氵 (water)	漆 (oil paint)
6	The meaning of the character is unrelated to the semantic radical.	金 (metal)	錯 (wrong)

Appendix II *Distribution of independent and extraneous variables*

Grade 1

Category	Semantic consistency	Strokes	Family size	Radical Frequency	Standalone	Character Frequency
LcTLs	0.41	13.9	26.2	506	0	2.7
LcOLs	0.38	12.6	26	390.6	4	3.3
LcTHs	0.71	11.7	26.6	363.6	7	2.5
LcOHs	0.73	13.5	30.1	416.3	8	2
HcTLs	0.41	10.4	26.9	650	4	34.6
HcOLs	0.67	11.1	10.3	212.3	4	29.9
HcTHs	0.72	12.4	22.2	337.7	7	50.8
HcOHs	0.67	11.1	10.3	212.3	7	28.9

Grade 3

Category	Semantic consistency	Strokes	Family size	Radical Frequency	Standalone	Character Frequency
LcTLs	0.32	13.6	21.7	853.2	7	4.3
LcOLs	0.30	12.8	21.9	780.9	7	3.9
LcTHs	0.72	13.8	66.3	1675.9	5	2.8
LcOHs	0.70	15.2	60.2	1516.7	4	6.1
HcTLs	0.30	11.3	36	2661.1	5	126.3
HcOLs	0.31	12.3	23.8	1527.1	6	193.8
HcTHs	0.72	14.3	55	1234.6	6	79.2
HcOHs	0.73	12.7	49.9	1359.9	8	82.2

Grade 5

Category	Semantic consistency	Strokes	Family size	Radical Frequency	Standalone	Character Frequency
LcTLs	0.26	14.9	42.3	3308.5	4	5.8
LcOLs	0.25	13.2	35.2	2385.7	6	8.7
LcTHs	0.74	12.1	99.2	4847	6	7.2
LcOHs	0.73	13.4	95.2	4655	6	7.4
HcTLs	0.27	13	48.4	4454.8	5	81.7
HcOLs	0.26	14.1	44.2	3503.5	3	260.6
HcTHs	0.72	13.6	85.7	4032.1	5	167.4
HcOHs	0.75	12.4	76.8	3846.7	5	202.4

Appendix III *Samples of Booklet and answer sheets*