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The development of visual chunking skills in perception of Chinese characters of Hong Kong children with different levels of literacy

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The development of visual chunking skills in perception of Chinese characters of Hong Kong children with different levels of literacy

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Research findings in visual chunking skills in Chinese character processing have suggested that visual chunking skills facilitate children's performance in character copying and they develop with learning experience. However, the relationship between visual chunking skills and levels of literacy has not been studied explicitly. This study aims to investigate the development of visual chunking skills of Hong Kong primary school children and its relationship with literacy levels to provide a better understanding of the cause of reading difficulties.

This study used a delayed-copying task with stroke-patterns and twelve types of characters, differing in character familiarity, radical familiarity, number of strokes, and number of units. One hundred and ninety-six children from three main stream primary schools in Hong Kong were recruited and divided into three groups according to their comprehensive Chinese ability as reflected by their assessment results in Chinese subjects. This study included analyses of both accuracy and errors. Analysis of variance (ANOVA) and post hoc tests were conducted for any significant group differences in performance in the delayed-copying task. In accuracy analysis, children with low literacy and children with special learning difficulties (SLD) performed more poorly than children with high literacy; but they did not consistently differ from each other. Older children performed better than younger children in every stimuli type. The main effects of character type, grade, and literacy were all significant in every comparison (p < .05). In the error analyses, it was found that younger children made more low-level errors than older children, suggesting that their visual chunking skills were lower than those of older children. SLD children, as expected, produced more low-level errors than their counterparts in the first grade, suggesting that their visual chunking skills were lower than those of children with high and low levels of literacy. This difference remained until the fourth grade.

To conclude, visual skills as well as visual chunking skills were found to develop with schooling, such that older children were at a higher level than younger children, suggesting a positive relationship between print exposure and character recognition. Children with both high and low levels of literacy possessed more advanced visual chunking skills than children with SLD. However, the evidence was less conclusive when children with low literacy and children with SLD in the second grade were compared. Nevertheless, the difference in literacy levels remained in the fourth grade. The visual skills in character processing differed between children with different levels of literacy in the first grade and the difference was attenuated in higher grades.

[Keywords]

visual skills visual chunking skills levels of literacy

special learning difficulties

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis represents is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written nor materials which has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

_______________________________ (Signed)

Pak, Keng Hong

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Chapter 1

Introduction

Studies of the alphabetic system have displayed evidence that different levels of orthographic information are extracted when reading words. The legality of spelling influences word recognition, such that the recognition of real words is better than that on pseudowords, which, in turn, is better than that of nonwords. This implies that familiar letter patterns facilitate the processing of words (e.g., “pen” in *carpenter;* “tion” in *dictionary;* and “pen” and “tion” in *compensation*). Children learning to read an alphabetic language, such as English, need to gain *metalinguistic awareness*, which is the mapping of phonemes on to letters (Shu & Anderson, 1999), since English is a Grapheme-Phoneme Correspondent (GPC) language.

However, learning to read Chinese is much more complicated. Although some consider there to be no such GPC rule in Chinese, Ho and Bryant (1997b) suggest that there is a certain degree of script-sound regularity in Chinese, referred to as the “orthographic-phonology-correspondent” (OPC) rule in Chinese characters. In fact, in the Chinese character system, one syllable can represent several characters; meanwhile, one character can have more than one pronunciation. According to the Xin Hua dictionary (1989) in Putonghua, one syllable can represent 17 characters on average (in the background of Putonghua, the following are the same), regardless of the intonation. Seven hundred characters are found to have multiple pronunciations occupying 10% of the 7000 characters in common use, i.e. one out of ten characters has multiple pronunciations. This indicates that in a writing-to-dictation task, the recognition of Chinese characters should mainly rely on the orthographic information provided by those characters. The same morpheme (character/word) may also carry different phonological addresses in both English and Chinese. For example, the Cantonese, “長” can be pronounced as dzoeng2, in “長大” /grown up/, or /tsoeng4/ in “長度” /length. Another example is the word, record, which can be pronounced as /'rɛkəd/ as a verb and /ri'kɔrd/ as a noun in English. Although this condition is not common in the lexical system, it can frequently cause mispronunciation. The linkage between phonology and orthography in Chinese is weakened, not only because of irregularity in pronunciation but also as a result of the homophones. This phenomenon does not conform to the said OPC and GPC rules. Chinese characters represent morphemes that have their own meanings, rather than phonemes. They are more pictorial or symbolic in concept, as they are comprised of strokes in various combinations. Most Chinese characters comprise a semantic component and a phonetic component. For example, “請”[/tsing2/, please] is comprised of a semantic component “言”[/jin4/, related to speaking] and a phonetic component “青” [/tsing1/, green]. Although phonological awareness is involved in Chinese reading, it is less significant in developing reading skills in Chinese than it is in English. Further, visual skills have been found to be more important in developing Chinese reading skills (Nobuko, 1996; Huang & Hanley, 1995; Shu & Meng, 2000; Taylor, 2002). Many studies have adopted a correlational method to study the relationship between visual ability and Chinese reading performance, with children’s visual ability being measured and tabulated (Ho, 1997; Ho & Bryant, 1999; Meng, Zhou, Zeng, Kong, & Zhuang, 2001; Siok & Fletcher, 2001; Sugishita & Omura, 2001; Zhang, Zhang, Chang, & Zhou, 1998). However, the more analytic and holistic processing mechanism adopted for characters is different from that used in the processing of figures. The evaluation of children's visual skills in character perception should therefore be based on materials related to characters.

A number of studies (Huang, 2001; Ku, Anderson, Li, Wu, & Hao, 2002; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003) recently have investigated the difference in reading ability and methods of character processing in children, in terms of visual chunking, by using *delayed-copying* tasks. In the task, target characters were briefly presented one by one and subjects were instructed to reproduce the characters after each presentation. To complete the task accurately and efficiently, the subject needed to 'chunk' **(**the process of combining the information from small units into the larger *chunks***)** the visual information of the characters (*visual chunking skills*). The delayed copying task used in these studies was able to illustrate the development of the visual chunking skills and the orthographic awareness in character recognition. Older children were found to possess a higher level of visual chunking skills than younger children. Older children mastered the visual chunking skills and applied the skills in the visual perception task more skillfully than younger children (Huang, 2001; Ku, Anderson, Li, Wu, & Hao, 2002; Pak et al., 2005; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003).

Ku et al. (2002) correlated school children's visual chunking skills with their reading abilities by using a delayed-copying task. They found that the fourth graders who had not developed sufficient visual chunking skills were likely to encounter reading difficulties. The relationship between *visual chunking skills* and reading ability in younger children needs further investigation. In addition, the development of visual chunking skills of children with *special learning difficulties* (SLD) has yet to be addressed. These SLD children may be qualitatively different from those with *low literacy levels* but the two groups have often been considered together as one “united” group. The investigation of the deviation in processing characters enables us to understand the etiology of reading problems. One of the goals of this study was to demonstrate a finer picture of the development process of visual chunking skills as well as the literacy difference in reading.

Research Questions

Previous studies investigating visual skills were carried out in Beijing where methods of character teaching and language experience differ considerably from Hong Kong, possibly leading to visual skills differences in character processing. This raises certain questions, e.g. (1) Do the visual skills, as well as visual chunking skills in character processing differ between children in Hong Kong and in Beijing? (2) Is the deviation in the application of visual chunking skills in children with different levels of literacy only to be found in Hong Kong’s senior grade students, or can it be seen in younger children as well? (3) The question of whether there are differences in the development of visual chunking skills between children with SLD and those with low level literacy has never been explored. To answer these three questions, this study aims to investigate the development of visual skills, visual chunking skills, and their relationships with Chinese literacy in character processing in Hong Kong primary school children.

How do beginners learn to perceive Chinese characters and how do they develop perceptual strategies while reading exposure accumulates? Is there any difference between children of different literacy levels? In view of the features of Chinese orthography, such as the construction and separation of the chunks, it may be expected that children with SLD develop skills with characteristics that are different from children with either low or high literacy. In summary, the main objectives of this study are three-fold: (1) To assess, first, whether there is a linear development of visual skills in character recognition according to age and, second, to investigate any difference in character recognition at different levels of literacy; (2) To investigate the development of the levels of visual chunking skills in a population of primary school children across grades; and (3) To determine whether children with different levels of literacy possess different levels of visual chunking skills. The author here defined *visual skills* as the ability to remember unfamiliar characters by rote, and *visual chunking skills* as the ability to perceive characters by chunks. The hypotheses of this study are that both visual skills and visual chunking skills develop with grades, and that there is a difference in the development of these two skills between children with different levels of literacy.

Overview of the study

In Chapter Two of this thesis, I will first discuss the features of Chinese characters and relative studies in Chinese characters. Issues related to visual skills and visual chunking skills in Chinese character processing are reviewed. The hypotheses of this study are also detailed. Details of methodology are provided in Chapter Three, including sampling, material information, experiment procedure and an introduction to the statistical methods used in data analysis. Detailed statistical methodology and the results of accuracy analyses and error analyses are presented in Chapter Four. Chapter Five presents a general discussion, which includes suggestions for results-based teaching, limitations of the study, and directions for further research.

Chapter 2

Literature Review

Because of the special features of Chinese characters when compared with the alphabetic system, and their value in the following argument, the discussion of important features of Chinese characters will be presented first, followed by a review of studies that have focused on the perception of Chinese characters. The review will explore the role of visual skills and visual chunking skills in character processing, as well as the factors related to reading performance. The chapter will conclude with a presentation of the hypotheses of this study.

2.1 Characteristics of Chinese characters

Strokes are the smallest unit of the Chinese writing system, the equivalent of letters in the alphabetic system. Chinese characters are not simple combinations of strokes but must be constructed according to certain rules. According to Fu (1993), there are five main types of strokes used in Chinese character formation, "一" [horizontal], "丨" [vertical], "丿"[left-falling stroke in calligraphy], "乛" [continuous stroke varied in direction], and "丶"[drop]. The simplest character has only one stroke (e. g. "一" [one]) while the most complex character has 36 strokes (e.g. "齉" [nasal]) (*Xian Dai Zhong Wen Ci Dian*, 1997).

Currently, there are two Chinese character systems: simplified and traditional. In 1956, the Chinese Government spearheaded a revolution in the writing of Chinese characters, resulting in the simplification of more than 2000 characters. Generally, the mean number of strokes in traditional script is 2.2 strokes more than that of simplified script (Ho, 2003). The number of strokes decides the visual density and the complexity of characters. In the simplified system, approximately 33.64% of the 7000 commonly used characters have 5 to 9 strokes and 44.65% take 10 to 14 strokes (Chang, 1993). Besides the number of strokes, the measures of the strokes (e.g. the length of stroke, whether it is sealed or not, over the character or not) produce different characters. For example, the characters, "田" [field] "甲" [excellent], "由" [because of], and "申" [a family name], are comprised of same strokes but have different meanings because of the length or the different position of the stroke "丨".

About 5% of the Chinese characters in regular use are single-unit characters (Huang & Hu, 1990). The single characters cannot be further broken down into meaningful components. For example, "我" [I], "日" [sun], and "天" [day] are all single-unit characters, which cannot be spatially separated. These single-unit characters are the units of the remaining 95% of compound characters. About 70-80% of these compound characters are phonetic compound characters that are comprised of one phonetic unit and one semantic unit (Wang & Zhou, 1999). According to reports, there are 246 semantic units (Kang, 1993) and 1,325 phonetic units (Li & Kang, 1993) in the simplified Chinese system. *Semantic radical* is the term used to indicate semantic units, while *phonetic radical* is used to indicate phonetic units in this study. The semantic radical might indicate the meaning of the character while the phonetic radical might provide hints on the character's pronunciation. The pronunciation and meaning of characters can be partly deduced. Only 77% of phonetic radicals can provide useful hints on character pronunciation; meanwhile 83% of semantic radicals can provide useful hints on character meaning (Wang, 1997). For example, characters with the phonetic radical “馬”[/maa5/, horse], such as “媽”[/maa1/, mother], “嗎”[/maa1/, modality particle], “罵”[/maa6/, abuse], and “螞”[/maa5/, ant] are pronounced /maa/ despite the difference in tones. The semantic radical “衤” means “cloth” or “related to cloth” in “袖”[sleeve], “褲”[trousers], and “被”[quilt], but such a meaning cannot be inferred in “初”[initial]. Moreover, the functions of phonetic and semantic radicals bring uncertainty as the functions may vary from character to character. For example, “色” [/sik1/, color] is the phonetic radical in “銫” [/sik1/, a kind of metal], but acts as semantic radical in “艷” [/jim6/, colorful]. This suggests that the functions of phonetic radicals and semantic radicals are not absolutely congruent. As the majority of Chinese characters are compounds of structures, this should attach importance to how readers detect characters, a significant issue that needs to be clarified.

Multi-level construction is an important feature of Chinese characters. A phonetic radical may be comprised of two or three subradicals. For example, the phonetic radical of “昭” [obvious] is “召” [call] and is comprised of two subradicals, “刀” [knife] and “口” [mouth]. But “昭” itself is the phonetic radical of “照” [shine], and is comprised of three subradicals, “刀” [knife], “口” [mouth], and “日” [sun]. Therefore, compound characters can be separated into components at different levels. For example, the first component level of “照” is “昭” and “灬”. The second component level is “日” and “召”. The third level is “刀” and “口”. Units such as “刀” and “口” are basic radicals (or pure radicals) that are not further decomposed. Such construction units of compound characters are single-unit characters. Peng (1997) used the concepts of direct radicals to indicate the components of the first level, as they are directly comprised of the whole character and directly express the meaning of the character. Components in the second and third levels are labeled *subradicals*. Fu (1993) found that approximately 648 subradicals can be decomposed from phonetic and semantic radicals.

About 327 character-radicals, accounting for 50.4% of 648 basic radicals (Fu, 1993) are called *free forms*. These free forms are morphemes and have their own meaning. The remaining 49.6% basic radicals are non-character-radicals are called *bound forms*. These radicals must attach to other radicals to convey their meanings. For example, the character "聽" [listen] is comprised of two direct radicals, " 耳 " [cannot be translated] and "悳" [cannot be translated]. The two radicals are bound forms which themselves do not carry meanings. The former is comprised of two meaningful subradicals, "耳" [ear] and "王" [king]; while the latter is comprised of four meaningful subradicals, "十" [ten], "四" [four] , "一" [one] , and "心" [heart]. The six subradicals have meanings that are free forms. Another example, the character "絳" [crimson], is comprised of two bound form radicals, "糸 " [related to silk] and "夅" [cannot be translated]. The latter is comprised of two bound form subradicals, "夂" [cannot be translated] and "㐄" [cannot be translated]. Irrespective of the radicals or subradicals, the meaningless bound form radicals are fixed stroke gatherings with assigned meaning, and are different from arbitrary stroke-patterns or meaningless irregular stroke gatherings.

The multi-level construction leads to the possibility of spatial separation of Chinese characters and therefore, the demand for chunking skills. According to Law and Leung (2000), both the spatial separation and the replacement factor of character components were two common rules in the logographeme perception of a character. Law and Leung believe that those spatially separated chunks should be analyzed further if they are comprised of components—logographemes that could be replaced. Take their example of "廟" [temple]; the said character could be divided into "广" , "𠦝", and "月" [moon]. "广" and "月" are not separable and "𠦝" can be further broken up as "十" [ten], "日" [sun], and "十". It was because the top"十"can be substituted by "立" [stand] and form "章"[chapter], or be removed to become "早" [early]. "日" can be replaced by "立" in "早" [morning] to form "辛" [hard]. Furthermore, the bottom "十" of "早"can be replaced by "干" to form "旱" [drought]. Therefore, the chunk of "𠦝"includes three logographemes: "十", "日", and "十". This suggests that the replacement factor of logographemes influences the perception of Chinese characters.

2.2 Studies of Chinese characters

As the special features of Chinese characters could implicitly influence character processing, many studies have been conducted to investigate the differences in various aspects of character processing, such as phonological (related to phonetic radicals), morphological (related to semantic radicals), and orthographic processing. Here I will focus on the studies that relate to orthography.

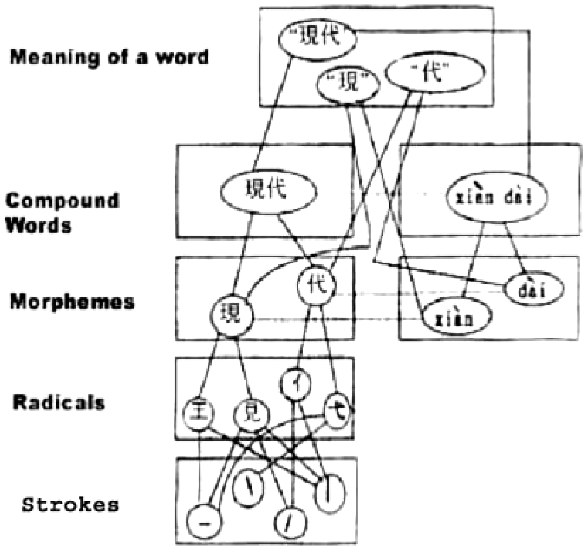
2.2.1 Chinese character processing models

The research content and methods of the processing units of Chinese characters have been informed by the alphabetic systems. Thus, I will briefly introduce three opinions on the unit of recognition in alphabetic systems. The first, proposed by Just and

Carpenter in 1987(see for review Zhang & Feng, 1992), is that the time spent focusing on words was prolonged when the length of words was extended. Just and Carpenter observed that people first analyzed letters and then integrated them into the whole word. The second concept, "whole word perception", was developed by Smith in 1972 (see for review Zhang & Feng, 1992). He regarded the recognition of words was the basis of whole word figures and shapes. The third idea, the "letter-integration model", was proposed by Cough in 1972 (see for review Zhang & Feng, 1992). In his opinion, a letter recognition stage preceded the recognition of words. The information from the letters was then integrated into the word information, e.g., the meaning of the word in the third stage. Cough's opinion combined the views of Just, Carpenter and Smith.

In Chinese studies, several models have been proposed and evaluated to determine their value in explaining Chinese character processing. These include the Chinese Multilevel Interactive Activation Model (CMIA) proposed by Taft and Zhu in 1994 (Taft and Zhu, 1997b), the Recognition-by-component model (RBC) proposed by Huang and Wang in 1992 (Huang & Wang, 1992) and the Model of Connectionism proposed by Chen and Peng (Peng, 1997). These models attempt to explain the processing of Chinese characters, describing the unit of processing, the activation modes of orthography, phonology, and semantics. However, consensus has yet to be reached. The author proposes to introduce a model that focuses on orthographic processing.

The *Chinese Multilevel Interactive Activation Model* (CMIA) proposed by Taft and Zhu in 1994 (Taft & Zhu, 1997b), is founded on the basis of connectionism, which reveals the hierarchical relationships between strokes, radicals (components), and characters in character recognition (See Figure 1). Taft and Zhu suggested that there are two routes in character processing. One route deals with phonological information and the other deals with orthographic information. This author will not discuss the phonetic representation but will focus on the orthographic route. The orthographic route moves from strokes to radicals, radicals to characters, and characters to words (compound characters).



—Adopted from Taft & Zhu (1997b)

Figure 1. Chinese Multilevel Interactive Activation Model **(**Taft and Zhu, 1997b**)**

Each level includes many different units and each unit relates to the others within and between levels. When a character is presented visually, the units of strokes are activated first. The activation spreads to the radical level and reaches the character level. The activation can spread into the higher or lower level to strengthen the interactive activated level of the lower level. The character will be recognized when the activation reaches the threshold. However, the CMIA model does not support the explanation of the role of character-radicals that are also single characters.

2.2.2 The functional units in character processing

Strokes or Radicals?

The CMIA model assumes that the analysis of strokes is essential for character identification; however, the model does not include the role of radicals in character processing. Although study results have identified different ideas of the processing unit, a consensus has not yet been formed. Studies of Chinese characters presented evidence of an effect from the number of strokes, regardless of whether the frequency of the characters was high or low (Peng & Wang, 1997; Wu & Zheng, 1982; Zeng, Zhou, & Yu, 2000; Zhang & Feng, 1992). Moreover, in other studies, the number of strokes played an important role in the reaction time and accuracy in the speed processing task (Chen, Allport, & Marshall, 1996; Yu & Cao, 1992b). Chen, Allport and Marshall (1996) found that not only the number of strokes, but also the number of radicals influenced character processing. Their study used an on-line (computer based) task to investigate the function of orthographic units (components or radicals) in Chinese character recognition. Twelve skilled Chinese readers participated. The stimuli used included characters, pseudo-characters (the position of the radicals was correct but the combination did not produce a real character), and non-characters (the position of the radicals was incorrect and thus the combination did not produce a real character). The number of units and the number of strokes were matched within each pair of stimuli that were made up by same item type (e.g. both were characters, pseudo-characters, or non-characters). The task of subjects was to judge whether the two stimuli of each pair were the "same" or "different"; this was labelled the simultaneous “same-different” (S-D) comparison paradigm. The major finding of this study was the effect of the number of radicals (stroke-patterns) while the number of strokes was controlled. The performance on the “same” trials of the skilled readers was influenced by the number of radicals; meanwhile, the performance on the “different” trials was influenced by the number of radicals that were different. Chen, Allport and Marshall proposed controlling the number of units but not the number of strokes and that the occurring integral stroke-patterns—components—but not the individual strokes, should act as the functional orthographic unit in the recognition of Chinese characters.

Their findings matched those of other researchers (Anderson, Li, Ku, Shu, & Wu, 2003; Fang & Wu, 1989; Ho & Bryant, 1997b; Huang & Hu, 1990; Liang, 1994; Lien, 1995; Meng, Shu, & Zhou, 2000; Peng & Li, 1995; Shu & Anderson, 1999; Wu, Zhou, & Shu, 1999; Xu, Alexander, & Potter, 1999; Yu, Feng, Cao, & Li, 1992; Zhang, Perfetti, & Yang, 1999; Zhou & Marslen-Wilson, 1999, 2002). In Fang and Wu’s study (1989), radical superiority effect was observed in character recognition in adult readers as characters segmented into their radical units were recognized faster than those segmented at the stroke level. Huang and Hu (1990) regarded single characters as the basic orthographic units of written Chinese. The role of these fixed, recurrent stroke-patterns can be likened to that of letters of the alphabet, which are the basic units of alphabetically written words, although the role of the said stroke-patterns in relation to character pronunciation is quite different from that of letters in the alphabetic system. These fixed, recurrent stroke-patterns may act as phonetic radicals and semantic radicals in compound characters. Zhou and Marslen-Wilson (1999, 2002) conducted a series of experiments with primed naming tasks to investigate the nature of sublexical processing. From an online semantic judgment task, they found evidence that from the very beginning of reading Chinese, phonetic components were decomposed from visual input and the phonological and semantic properties of the phonetic components were processed in parallel to the whole characters. The naming latency increased when the priming was semantically related to the target in the online naming task. Zhou and Marslen-Wilson concluded that the processing of Chinese characters was both a phonological and a semantic event as both phonetics and semantics were automatically activated in reading.

Subradicals?

It was suggested that the sublexicals of characters were the processing unit in character recognition. Moreover, other researchers have found that subradicals is also processed during the identification of characters (e.g. Fang & Wu, 1989; Lu, Wang, & Peng, 1996; Taft & Zhu, 1997a). Taft and Zhu (1997a), used 3-unit characters to investigate submorpheme processing in reading Chinese. The effect of subradicals was tested in compound radicals that were comprised of 2 radicals. The researchers found that the 'Response Time' (RT) was influenced by the frequency of the subradicals but not by the frequency of compound radicals. Taft and Zhu concluded that all simple radicals (subradicals) were independently activated in the process of character recognition. Compound radicals in the 3-unit characters were not activated despite their common occurrence. Taft and Zhu thus concluded that subradical frequency influenced character processing as effectively as character frequency. Supportive evidence was also found in the study by Lu, Wang, and Peng (1996). They used single unit characters, two-unit characters, and three-unit characters to investigate the number of unit effect. Skilled readers were recruited. It was observed that the response time for two-unit characters was the shortest while the response time for three-unit characters was the longest. It was surmised that subradicals implicitly influenced the perception of Chinese characters, which prolonged the RT. The findings presented clear evidence that the subradical was also the functional unit in character processing.

Peng and Wang (1997) conducted an overall study to investigate the basic processing unit in Chinese character recognition. The number of strokes and the number of radicals were controlled. They produced evidence to demonstrate that the processing of characters took place at three levels: stroke, radical, and whole character. They found that the response time (RT) was influenced by both the number of strokes per radical and by the number of radicals. Peng and Wang also investigated the differences between the processing of single-unit characters and multi-unit characters. They concluded that the processing unit of single-unit characters was strokes; whereas, the processing unit of multi-unit characters was both strokes and radicals. Generally, subradicals and direct radicals were regarded as the construction units but in different processing levels, while the stroke was the writing unit of Chinese characters.

Characters?

Besides strokes, subradicals, and radicals, the processing of the whole character was also investigated. Character frequency has been well documented as one of the most potent variables to influence character processing. In on-line lexical decision tasks, character frequency has a reliable negative correlation with RTs for correct judgments of character stimuli. The recognition threshold of 'high-frequent' characters was lower than that of 'low-frequent' characters, so that the RT of high-frequent characters was shorter than low-frequent characters (Feldman & Siok, 1997; Lau, 2002; Peng, 1997; Pollatsek, Tan, & Rayner, 2000; Taft & Zhu, 1997; Takao, Matsuo, Karalyn, & Itaru, 1999; Zhou & Marslen-Wilson, 1999). Lu, Wang, and Peng (1996) found that the number of radical units influenced the performance of character recognition in low-frequent characters; this did not occur in high-frequent characters.

Characters with high frequency produce a tendency of anti-separation that constrains the recognition of each individual unit. Chen (1986) used a component detection task and found the components in characters were more difficult to be identified than the components in non-characters. The effect was more pronounced when the character frequency was raised. Chen found that high-frequent characters, as well as components with high frequency, were processed in a holistic way. The results of Chen's study indicated that familiar components of the characters or familiar characters were coded as chunks. Following the findings of their component detection task, Ku et al. (2002) supported Chen's conclusion. Ku et al. controlled the level of detected units—component and subcomponent to investigate the effect of the familiarity of different kinds of "characters". In their study, 'components' referred to the phonetic radicals and semantic radicals that comprised compound characters directly; 'subcomponents' referred to the units or meaningful stroke-patterns that comprised compound radicals, especially phonetics. Ku et al. found that the component detection performance of children in characters was the poorest; pseudo-characters came the second, and the best performance was of non-characters. In such a case, the familiarity of components and radicals, as well as the effect of the number of strokes, were ignored. More consistent findings were extensively reported where characters with high frequency were processed in a holistic way (Chen, 1999; Chen, Allport, & Marshall, 1996; Guo, 2000; Lau, 2002; Leck, Weekes, & Chen, 1995; Takao, Matsuo, Karalyn, & Itaru, 1999; Taft & Zhu, 1997). Such findings suggested that high-frequent characters were automatically recognized when processed holistically and characters with low frequency were processed with an analytical strategy through visual imagery.

Proposed processing flow

From the above review, I would like to propose that character processing follows a principle path, from holistic to analytic. When a character was visually presented, the identification began from the biggest unit—the whole character. If the character was familiar, the processing unit was the whole character; otherwise, the identification processing would continue and enter lower processing unit, eg. the radical and subradical for compound characters or strokes for single-unit characters. If the radicals or subradicals were familiar, the unfamiliar character was processed through the familiar radicals or subradicals, that were processing units. The exploration would be discontinued once the unit was recognized or it would progress to strokes if the unit was unknown. The proposed flow is displayed in Figure 2.

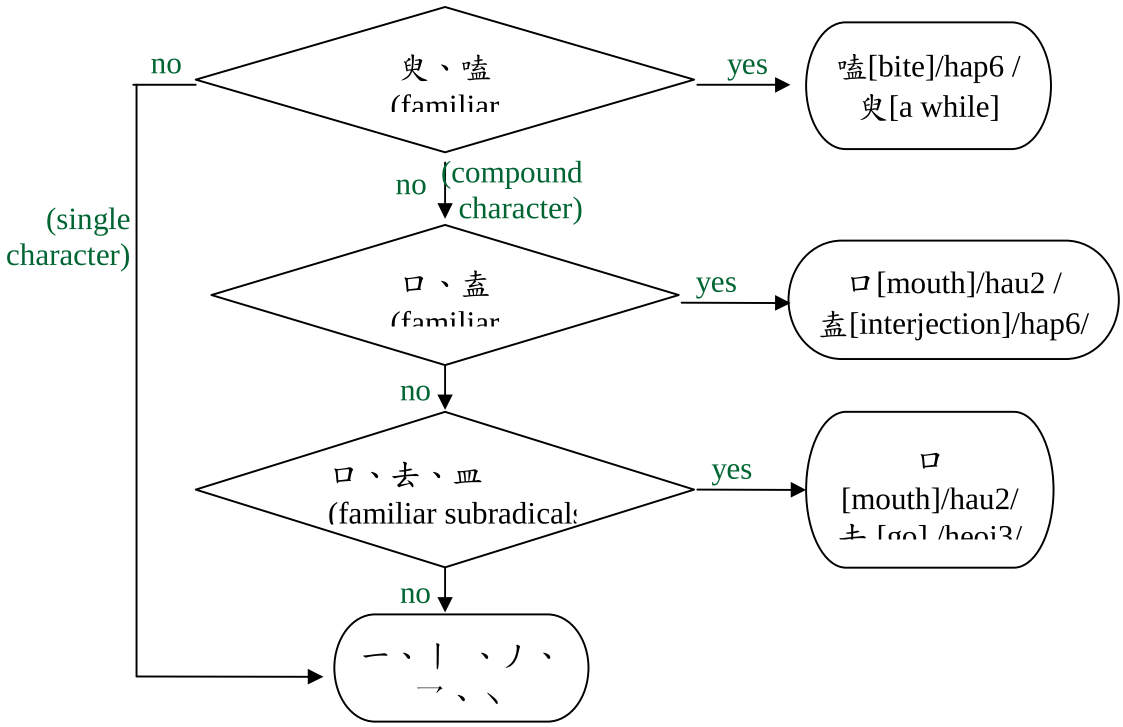


Figure 2. Proposed flow of process in character recognition

2.3 Visual skills influence the perception of Chinese characters

Studies in the alphabetic system found dyslexics had more advanced orthographic skills than normal readers to compensate for weak phonological awareness (Siegel, Share, & Geva, 1995; So & Siegel, 1997; Stanovich & West, 1989). For example, So and Siegel (1997) provided evidence that the visual short-term memory (STM) of poor readers was inferior to that of normal readers. On the other hand, Edwards (2000) found the visual processing skills did not significantly differ between skilled readers and those with reading disabilities. Some contrast studies in Chinese found more consistent results on the role of visual ability in reading (Ho, Chan, Tsang, & Lee, 2002; Huang & Hanley, 1994; Meng, Zhou, Zeng, Kong, & Zhuang, 2001; Zhang, Zhang, Chang, & Zhou, 1998). Ho and her colleagues (2002) explored the cognitive profile of Chinese developmental dyslexia. Dyslexic children, chronological age control children, and reading level control children were recruited. It was found that rapid naming was the most dominant type of cognitive deficit of dyslexics, while orthographic deficit and visual deficit took the second and third place. Meanwhile, phonological awareness was not identified as being significantly dominant in Chinese dyslexic children. Ho’s study suggested that the lack of visual processing ability was one of the main cognition features of the Chinese reading disabled. Meng et al. (2001) investigated the influence of children’s visual perceptual skills on other reading activities. They concluded that visual perceptual skills mainly influenced the recognition process of elementary visual analysis and orthographic recognition.

Huang and Hanley (1994) conducted a further study to test the role of phonological awareness and visual skills in learning to read Chinese and English. One hundred and thirty seven 8-year-old primary school children from Britain, Hong Kong, and Taiwan were given phonological tasks, visual matching tasks, and reading tasks. Results showed that the performance in phonological tasks, such as rhyme and phoneme detection, were strongly correlated to reading ability in British children, but this correlation was not as strong in Hong Kong and Taiwanese children. Moreover, visual skills were distinguished to be an important factor of reading ability in Hong Kong and Taiwanese children but not in British children. Though Huang and Hanley found a link between visual skills and reading ability, in their follow-up study they found that visual skills did not act as a predictor of later reading ability (Huang & Hanley, 1997). In a Japanese study, Nobuko (1996) observed that, in learning Japanese, subjects whose first language was Chinese relied more on the visual information of Japanese Kanji (a system developed from Chinese) than those whose first language was English. Taylor (2002), after a review of relative studies, concluded that phonological awareness was less important in Chinese reading than in English reading; meanwhile, visual skills played a more important role in Chinese reading.

The findings concerning the role of visual skills in reading were inconsistent in the alphabetic and orthographic systems. Studies were conducted to explore the reasons behind the differences in the strategies readers adopted and the skills they used in processing logographic script and alphabetic script (Chua, 1999; Ho & Bryant, 1999; Sugishita & Omura, 2001). Sugishita and Omura (2001) used visual tasks to test 316 Japanese and 316 Americans aged from 17 to 74 years. All age groups in the Japanese cohort obtained significantly higher scores than their American counterparts on two visual recall subtests. In addition, three Japanese groups performed significantly better than the Americans on the Visual Memory Span subtest. Sugishita and Omura suggested that learning Japanese Kanji (orthographic script) could improve visual recall ability. Ho and Bryant (1999) investigated the possibility of visual precursors in Chinese and English speaking children, concluding that visual skills were important in learning both Chinese and English but the skills used in the two systems were different. Moreover, Chua (1999) observed different processing strategies between the alphabetic system and the orthographic system. Chua asked both Chinese readers and non-Chinese readers to judge whether pairs of presented paired targets were the same or not. The targets either paired a whole character or just paired the right or the left component. It was found that Chinese readers processed characters in a holistic way and that non-Chinese readers processed the characters by separating the components. The finding, that the role of visual skills was different in alphabetic orthography and Chinese orthography, indicated that the learning experience (alphabetic or logographic) implicitly influenced the processing method.

When compared with alphabetic scripts, the Chinese character is clearly more complex. The features of Chinese characters are many: the complexity of orthography, the number of units, the structure of the character, the character frequency, and the spatial separability all influence character processing (Chen & Allport, 1995; Law & Leung, 2000; Li, Fu, & Lin, 2000; Taft, Zhu, & Peng, 1999; Wang & Sun, 1998; Yeh, 2000; Yu & Cao, 1992a, 1992b; Zeng, Zhou, & Yu, 2000). The recognition of Chinese characters depended primarily on the orthographic information provided by characters. This might stem from the perception of the features of Chinese characters, i.e. a process of perception from orthography (visual) to phonology; while the perception of alphabetic writing proceeded from grapheme to phoneme. The complex combination of relationships between components of Chinese characters, for example, left-right, top-down, encircled and semi-encircled, requires readers to develop a high spatial discrimination ability in order to recognize characters correctly.

As visual skills were found to be important in the process of Chinese character recognition, some researchers have suggested that the visual skills in character processing could be used as predictors of later reading ability as well as phonological awareness and naming speed (Ho, 1997; Ho & Bryant, 1999; Siok & Fletcher, 2001). Ho (1997) used abstract figures to investigate the relationship between visual skills and reading achievement in second graders. No significant relationship was found and it was concluded that visual skills were only important for beginning readers but not for more experienced readers. This conclusion was partly supported by other studies (Ho & Bryant, 1999; Huang & Hanley, 1997). Ho and Bryant (1999) conducted a longitudinal study of one hundred 4-year-old Chinese kindergarten children and fifty-two 4-year-old English children to examine the visual precursors of learning to read Chinese and English. They found that shape constancy was a strong predictor of Chinese children's later Chinese reading ability; whereas, spatial relationships, position in space, and figure-ground were significant predictors of English children's later English reading ability. Ho and Bryant then suggested that pre-reading visual skills were meaningful predictors of Chinese character reading for Chinese 4-year-olds who had been learning to read Chinese for approximately 3 months. They assumed that younger children depended more on their visual ability in character recognition. In addition, Huang and Hanley (1997) found that visual skills did not act as a predictor of later reading ability in children with more reading experience.

Besides the predictive function, McBride and Ho (2000a) found the function of visual skills was perceived to be more important in the task of speed processing. They administered a variety of reading-related tasks to eighty 3-4-year old Chinese kindergarten students in Hong Kong. The tasks included speeded picture and number naming, phonological awareness, visual attention, visual memory, vocabulary, letter knowledge, and Chinese character reading. The researchers found that slow naming speed was associated with relatively poor visual attention and letter knowledge; visual attention might, therefore, be an important component of speeded naming in young Chinese readers.

2.4 Visual chunking skills in orthographic processing

In early studies of Chinese characters, the inclusion of familiar components was found to facilitate character recognition. Furthermore, the presence of familiar components confounded the learning of unfamiliar components, such that unfamiliar components were replaced by familiar components (Cao & Shen, 1963). This suggests that the recognition of complex and compound characters relies not only on visual skills but also on the simple characters or single components that make up compound characters. These simple characters and single components are called chunks. *Chunking* is the process of combining the information from small units (e.g. strokes) into the larger *chunks* (radicals and subradicals). In effect, chunks are simply a re-organization or recoding of information. In the alphabetic system, the recurrent parts of words, for example, simple words, prefixes, and suffixes, are found as integral imagery—chunks in reading. Strokes and radicals are the functional processing units that were chunks at different levels in Chinese characters. *Visual chunking skills*, in other words, encompasses the ability to chunk strokes into bigger components of characters. It was concluded from the previous review that characters were identified through different levels of character components—chunks, which facilitated character processing (Huang, 2001; Ku, Anderson, Li, Wu, & Hao, 2002; Pak, et al., 2005; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003). The readers' efficiency in using the chunks of character exerted a definite and notable influence on their reading performances.

According to the hypothesis of chunks raised by G. A. Miller in 1956 (see for review Anderson, 1985; see for review Wang & Wang, 1992), fewer chunks facilitated more efficient cognition processing. This suggests that character identification would improve with fewer separations as well as a more advanced level of chunks. Taking the example mentioned previously, the processing of the character “聽” [listen] might differ from individual to individual. Skilled readers might process the character in a holistic way, i.e. as a whole character, or in a less efficient way, in which the character was perceived as two components “耳 ” and “悳”, as the two stroke combinations always appear together. In less skilled readers, the character might be separated into more chunks—radicals of “耳” [ear] , “王” [king], “十” [ten], “四” [four], “一” [one], and “心” [heart], which required more capacity of working memory and occupied more resources of long-term memory. According to Zhang and Simon (1985), acoustical short-term memory has a capacity of up to seven chunks; short-term memory capacity for material encoded non-phonologically appears to be no greater than three chunks. Therefore, to process a complex Chinese character efficiently and accurately, it was necessary to reduce the profound or visual information to no more than three components. It was clear that visual chunking skills play a decisive role in the early stage of character processing. The concept of chunks and the strategy of chunking was of great importance to Chinese reading. Children with different reading levels should have different concepts in using the chunking skills and thus have different reading abilities that determined their reading performance and its variance.

Methods used to investigate visual chunking skills

Recent studies cast light on the role of visual chunking skills in reading Chinese (Huang, 2001; Ku, Anderson, Li, Wu, & Hao, 2002; Pak, et al., 2005; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003). In these studies, visual chunking skills were investigated through *delayed-copying task* and *component detection task*. In the delayed-copying task, target characters were printed in black on white A4 size paper. The task was conducted in the form of groups, mostly classes. One character was presented briefly for two seconds and then covered. The subjects were then asked to reproduce the character. In the component detection task, subjects were asked to detect the "characters" with the target component from lists of characters. The target component included free form components (character-components) and bound form components (stroke pattern-components). The target characters could be a real character, pseudo-character, or non-character. *Pseudo-character* is defined as the components of the character in their legal positions obeying the orthographic rule but failing to produce a real whole character. For example, "" is a pseudo-character where both components are in their legal positions but the whole is not a real character. *Non-character* is defined as a combination where at least one of the character components is in an illegal position that breaks the orthographic rule. For example, "" is a non-character, as the right hand component has never been positioned on the right.

It is clear that processing unfamiliar information into meaningful units is important to enhance cognition skills. Visual chunking skills were considered to be closely related to reading ability (Hao, Zhang, & Chen, 1983; Ku, Anderson, Li, Wu, & Hao, 2002; Woo & Hoosain, 1984). Woo and Hoosain (1984) used a character recognition task to investigate the role of visual perception in Chinese reading. Subjects were briefly shown a list of characters and subsequently asked to identify the target characters from another list of characters that included target characters and three distracters that were phonologically, semantically, or visually similar to the targets. Children with reading difficulties deviated from average readers primarily in their susceptibility to visual confusion, suggesting that visual processing disabilities in Chinese character recognition might be the primary cause of reading difficulty in Chinese. Ku et al. (2002) also used a delayed-copying task to examine the visual chunking skills of primary school children in Beijing. They found that reading ability and perceptual chunking ability were highly correlated in the fourth graders and concluded that children in senior grades who had not developed perceptional chunking skills were likely to encounter serious reading problems. Accordingly, visual chunking skills influenced the learning of Chinese characters. Ku et al. (2002) used a component detection task to investigate the perception ability of character chunks in school age children. They found that children as young as first grade had some awareness of the internal structure of Chinese characters—some of these children were able to encode characters into major component chunks. This strategy facilitated the performance of character recognition. The function of visual chunks of Chinese characters was emphasized. Shu et al. (2003) adopted the delayed-copying task to investigate the development of orthographic knowledge of Chinese characters in Beijing children. It was suggested that the reading performance of children was greatly influenced by the properties of character components. Component representation levels were specific to school ages. Moreover, younger children were found making more stroke-related errors, which implied that younger children decomposed characters into chunks on a lower level, such as strokes and simple stroke-patterns. Both Ku and Shu drew the conclusion that visual chunking skills were enhanced with schooling.

It is speculated that the concepts of processing units may vary between individuals with different reading experience and abilities. For example, beginners may regard strokes as the basic units of Chinese characters, whereas more experienced readers may regard radicals, even familiar characters, as the basic units. Though children with different reading abilities were not shown to possess different levels of chunking skills, the evaluation of the development of chunking skills might have the potential to provide hints for identifying those with special learning difficulties. It would be useful to know whether the visual skills and visual chunking skills in character processing differed between children with different reading abilities.

2.5 Hypotheses

Using information obtained from the above reviews, this study was designed to investigate the visual chunking skills as well as visual skills in character reading by delayed-copying task in Hong Kong primary school children.

Visual skills

A factor analysis named *visual skills* that depended on all stimuli types, was conducted to determine to what degree the variance of performance depended on visual skills.

The first aim of this study is to investigate whether the visual skills in character processing varied between children of different ages and with different levels of literacy. Previous studies investigated children's visual ability, mainly by assessing their performance on the processing of pictorial representations (Ho & Bryant, 1999; Ho, Chan, Tsang, & Lee, 2002; McBride & Ho, 2000a, 2002b; Meng, Zhou, Zeng, Kong, & Zhuang, 2001; Siok & Fletcher, 2001; Sugishita & Omura, 2001; Zhang, Zhang, Chang, & Zhou, 1998). However, the mechanism of figure processing is different from that of character processing. Due to the characteristics of Chinese characters, when compared with the alphabetic system, character processing is more dependent on visual and spatial skills. Characters are processed in context and therefore the information of radicals is activated. The evaluation of children's visual skills in character perception should be based on materials related to characters.

Thus, Type 1 stimuli (arbitrary stroke-patterns), of irregular stroke combinations carrying no meaning, were designed to investigate children's visual skills in character recognition. A similar prediction is made for the performance in Type 3 (unfamiliar single-unit characters, C_{uf}_S_1) of which the characters are unfamiliar pure-radicals. Both unfamiliar single-unit characters and arbitrary stroke-patterns cannot be further divided into meaningful units. The visual skills involved in arbitrary stroke-patterns and unfamiliar single-unit characters are maximal. Higher graders will perform better than lower graders in both types, as they are assumed to possess more mature visual skills. Moreover, the visual skills of children with SLD may be better than their peers to compensate for the deficit in other aspects.

The development of the visual chunking skills

The second purpose is to investigate the development of the visual chunking skills in character recognition in Hong Kong children. Different types of characters are designed, with each two comparable types differing in one character feature only. The differences between the comparable types will indicate different levels of visual chunking skills. Thus, while the familiarity of characters and radicals, and the number of strokes are controlled, the use of chunks in the task will be found more important. There are several hypotheses and predictions:

(1) *Character-chunk*. It is hypothesized that if the chunking skills are applied on the level of the whole character, the performance on the four familiar character types, including Type 2 (familiar single-unit characters, $C_f\_S_1$), Type 4 (familiar simple two-unit characters, $C_f\_S_2$), Type 7 (familiar complex two-unit characters, $C_f\_S_{2m}$) and Type 10 (familiar three-unit characters, $C_f\_S_3$), will not change significantly, regardless the difference in the number of strokes and the number of units, as the degree of character familiarity corresponds to the degree of difficulty of chunking. Students with less sophisticated visual chunking skills will exhibit a poorer performance than students with more sophisticated visual chunking skills.

(2) *Radical-chunk.* It is proposed that if the processing unit is on the level of radical chunks, the performances will be similar in Type C_f (familiar characters, including Type 4, Type 7, and Type 10) and Type $C_{uf}\_R_f$ (unfamiliar characters with familiar radicals, including Type 5, Type 8, and Type 11). A smaller difference between the two groups indicates better use of radical chunks. The performance in Type R_f should be much better than that in Type R_{uf} (unfamiliar characters with unfamiliar radicals, including Type 6, Type 9, and Type 13). Performances in the three types will differ between students with different visual chunking skills. Students with more advanced visual chunking skills will perform better than students with less advanced visual chunking skills. The processing of unfamiliar characters with unfamiliar radicals requires more capacity of working memory and short-term memory; therefore, it is more difficult to chunk these characters with unfamiliar radicals than to chunk

unfamiliar characters with familiar radicals. Thus, all subjects will perform less effectively with this type of character, compared to their performance on unfamiliar characters with familiar radicals.

(3) *Subradical-chunk.* Both radicals and subradicals possess equal activation potential in character processing (Taft & Zhu, 1997a). This part of the analysis, aimed at investigating the role of subradical chunks in character processing, was ignored in previous delayed-copying studies. The performances in Type $C_{uf}\_R_{f}\_SR_{f}\_S_{3}$ (with familiar radical and familiar subradicals) and in Type $C_{uf}\_R_{uf}\_SR_{f}\_S_{3}$ (with unfamiliar radical and familiar subradicals) should be similar, as the subradicals of both types are familiar. Meanwhile, the performances in Type $C_{uf}\_R_{uf}\_SR_{f}\_S_{3}$ should be better than those in Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_{3}$, as the subradicals of $C_{uf}\_R_{uf}\_SR_{uf}\_S_{3}$ (with unfamiliar radical and subradicals) are unfamiliar. Performances will vary between students with different visual chunking skills in unfamiliar characters with unfamiliar radicals comprised of familiar subradicals (Type 12) and unfamiliar characters with unfamiliar components comprised of unfamiliar subradicals (Type 13).

Literacy difference in visual chunking skills

The third purpose of this study is to investigate whether visual chunking skills differ between children with different levels of literacy. Studies of Chinese readers found that many cognitive factors, such as naming speed, visual skills, short-term memory, and morphological awareness, as well as phonological awareness, were shown to be associated with early character identification, especially in young Chinese readers. The difference was more evident between readers with different reading abilities (Chan &

Siegel, 2001; Ho & Bryant, 1997a, 1999; Huang & Hanley, 1995a, 1995b; McBride-Chang & Ho, 2000a, 2000b; Shu & Meng, 2000). Delays and deviations in the development of reading skills were proposed as the cause of poor performance in reading. Some researchers suggested that some reading disabled had underlying difficulty in extracting the relevant features and invariants to form rules in both oral language and reading, thus making it difficult to develop efficiency in applying the hint system (Ho, 1999; Ho & Cheung, 1999; Muter & Snowling, 1997; Shu & Meng, 2000; Shu, Meng, & Cheng-Lai, 2003; So & Siegel, 1997). According to Ku and her colleagues (2002), those children who had not developed perceptual chunking skills in the fourth grade might have serious reading problem, which suggests that children with different reading abilities might possess different levels of chunking skills.

To conclude, in addition to the development of chunking with learning experience (Liang, 1994; Shu & Anderson, 1999; Shu, Anderson, & Wu, 2000), visual chunking skills may also differ between children with different levels of literacy. The above predictions for different age groups are similar for high-literacy-students, low-literacy-students, and SLD-students. The issue of how visual chunking skills influence the performance of children with different levels of literacy, especially the difference between children with SLD and children with low literacy, have not been formally addressed in the literature. These two groups remain unsegregated in the classroom. It was proposed that children with a higher level of literacy possess more advanced chunking skills than those with lower literacy. As a result, children with a lower level of literacy should demonstrate poorer performance than those with a higher level of literacy.

Errors

It is also the goal of this study to collect a set of data that will allow the investigator to understand the errors appearing in the task. Beginners are expected to be aware of the writing unit—strokes as the basic units of Chinese characters, whereas more experienced readers may chunk characters in a higher level—functional units, such as radicals that are directly comprised of characters. For example, "衤" and "刀" are functional units in detecting "初"，but the single strokes of the character, such as "丶" [drop], "一" [horizontal], "丨" [vertical], "丿"[left-falling stroke in calligraphy] etc., are not functional units. It is anticipated that some stroke errors will be found in the task, as the spatial, separable chunks provide an opportunity for the radicals to be replaced. Meanwhile, it is proposed that some replacing errors will be found in the task. Moreover, errors of inaccurate orthography representation will also be found (Luan, 2001; Luan, Shu, & Zhang, 2000; Meng, 2000; Pak, 2001, 2002; Pak, et al., 2005; Shu, Qian, Wu, Cheng-Lai & Tso, 2003). The error analysis will provide supplementary evidence to support accuracy analysis.

The neatness of handwriting

The correlation between rating of the neatness of children's handwriting and children's performance in the delayed-copying task will be measured to investigate whether there is correlation between the neatness of children's handwriting and their performance in the copying task. A high correlation should indicate that the performance coding in the delayed-copying task was influenced by the neatness of children's handwriting. Otherwise, consideration of the neatness of handwriting as a confounding variable could be neglected.

The thirteen stimuli types and the methodological design of this study will be described in greater detail in the following section.

Chapter 3

Methodology

3.1 Subjects

In previous studies, researchers have selected subjects at different stages of development to assess the characteristics of each stage (Liang, 1994; Peng & Li, 1995; Shu, 1997; Shu & Anderson, 1997; Shu & Zeng, 1996; Yang & Peng, 1995). Different aspects of metalinguistics were investigated to understand the development of different insights. Shu (1997) provided a comprehensive review of the acquisition of character construction regularity. Third graders[1] were assessed for their uniformity of Chinese character usage in character processing. Their use of phonetic information was found to be similar to that of skilled readers in senior grades. Liang (1994) investigated Chinese children's use of orthographic information and analogy process in learning to read Chinese. Liang found that even the first graders could use both phonetic clues and semantic clues when dealing with unknown characters, regardless of their overuse of the information. However, it was not until third grade that children began to develop more consistent "unit" awareness. Song, Zhang, and Shu (1995) found that adult readers depended primarily on phonetics in reading while Primary 3 children mainly depended on orthographic clues. The fifth graders with high Chinese ability were found to perform at a similar level of competence to adult readers in using phonetic clues, while the pattern of low ability children in the fifth grade was found to be similar to that of third grade children with average ability. This suggested that Primary 5 was the turning point, where children began to change from using phonetic to orthographic clues in reading. Other

[1] Note: average age for grade levels indicated in this study is: first grade – 6 years, second grade – 7 years, and fourth grade – 9 years

researchers reported that children did not acquire an awareness of semantics until grade 6 (Shu, 1997). In a study by Huang (2001), the second grade was speculated to be a critical period in orthographic development. Huang's findings indicated that cognitive ability varied according to the orthographic development stages reached. Thus, the current study selected grades one, two and four as the three development stages, following the practice widely adopted in previous studies (Ku, Anderson, Li, Wu, & Hao, 2001; Shu, 1997; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003).

One hundred and ninety-six Hong Kong pupils from three mainstream primary schools in Kowloon and the New Territories were recruited, sixty-five first graders, sixty-five second graders, and sixty-six fourth graders. Each group was classified into three literacy groups (High Literacy, Low Literacy, and Special Learning Difficulties) according to the following criteria commonly used in children's reading research: *1)* academic attainment test results in Chinese; *2)* nomination by Chinese teachers (Lu, 1995; McBride-Chang & Ho, 2000b; Shu & Anderson, 1997) and *3)* performance in *The Hong Kong Test of Special Learning Difficulty* (HK-SpSLD) (Hong Kong Education and Manpower Bureau, 1996). Children taking the SLD test were nominated by their teachers on the grounds that they were thought to have special learning difficulties. Students whose SLD results showed they were at risk of SLD were excluded from the study. "Academic attainment of Chinese subject" was derived from the children's performance in the school examination of Chinese, including assessment in listening comprehension, oral ability, reading comprehension and composition. Children with a normal intelligent quotient (IQ) but whose Chinese academic achievement fell below 30% of the class were placed in the low literacy group; similarly, the upper 30% were placed in the high literacy group. Those with low literacy but whose poor academic performance might be caused by some objective reasons were excluded on the recommendations of their teachers; exclusion criteria were as follows: new immigrants, possible mental retarded, motor coordinated problem, and "unwilling to learn". As a result, 90 children were classified as having high literacy, 90 as having low literacy, and 16 as having *special learning difficulties* (SLD).

The details of grouping information are displayed in Table 1. Parent consent letters were sent through the schools. The consent letter is attached in appendix II.

Table 1

Number of Subjects in each Ability-group by Grade

Level of Literacy	Grade			Total
	One (Average age=6)	Two (Average age=7)	Four (Average age=9)	
High	30	30	30	90
Low	30	30	30	90
SLD	5	5	6	16
Total	65	65	66	196

3.2 Materials

The materials used in the delayed-copying task were designed by manipulating the characteristics of Chinese characters, including visual complexity (in terms of number of strokes), the number of units, character familiarity, radical familiarity, and subradical familiarity. In total, 96 characters and 8 arbitrary stroke-patterns were designed. According to Huang (1986), 46.4% of the 7,254 Chinese characters in the Xin Hua

Dictionary are made up of three radicals or subradicals and 25.6% are made up of two radicals. Chen, Allport and Marshall (1996) designed stimuli with two and three units (radical or subradical). Only those compound characters being comprised of two and three units, were selected for use in this study. Moreover, the structures of characters were only manipulated by spatial separation. Although it would be ideal to consider how often radicals of characters appeared in primary school books, it was not possible to locate enough characters that met our requirements. In this study, the familiarity of the characters between different types was matched in character frequency (Bei & Zhang, 1988) as well as the familiarity of primary textbooks that were referred to the Hong Kong corpus of primary school Chinese (HKCPSC) (Leung & Lee, 2002). *Familiar characters* refers to those that have been learnt by the first graders in their Chinese classes; *unfamiliar characters* refers to those that have not been learnt by the fourth graders in their Chinese classes. In Ku, et al. (2002) and Shu, et al. (2003), familiar characters, radicals, and subradicals were regarded as chunks if the characters were learnt. For example, "礻" should be a familiar chunk in the unfamiliar character "禓" if "初" has been learnt; and "刀" should be a familiar chunk in the unfamiliar character "叨" if "刀" has been learnt. The familiarity of radicals and subradicals is defined in the same manner. Twelve types of characters and one type of arbitrary stroke-patterns were designed in this study. The details of the character types are displayed as follows:

Type 1 stimuli (SP) were arbitrary stroke-patterns, for example, "". These arbitrary stroke-patterns were comprised of real strokes of Chinese characters combined in an irregular way. Though the arbitrary stroke-patterns provide no indication of unit meaning, the process of copying arbitrary stroke-patterns should provide higher relations with visual skills used in Chinese characters processing than by processing geometrical figures. The mean number of strokes of the eight arbitrary stroke-patterns was 7.5.

Type 2 characters (C_{f}_S_1) were familiar single-unit characters. Single-unit characters were characters that could not be further divided into meaningful units through *spatial separability*, for example, "弟" [/dai6/, little brother]. The mean number of strokes was 7.63. The mean character frequency was 1631.1 per million (Bei & Zhang, 1988). Type 3 characters (C_{uf}_S_1) were unfamiliar single-unit characters, for example, "禹" [/jyu5/, a king of ancient China]. The mean number of strokes was 7.88 and the mean frequency was 29.8 per million.

Type 4 characters (C_{f}_S_2) were familiar two-unit characters, for example, "和" [/wo4/, with]. The mean number of strokes was 7.88. The mean frequency of this type of character was 2424.8 per million. Type 5 characters (C_{uf}_R_f_S_2) were unfamiliar two-unit characters, for example, "俚" [/lei5/, slang]. The mean number of strokes of Type 5 characters (C_{uf}_R_f_S_2) was 7.75 and the mean frequency was 17.2 per million. Type 6 characters (C_{uf}_R_{uf}_S_2) were unfamiliar two-unit characters with at least one unfamiliar radical, for example, the left radical of the character "卸" [/se3/, unload] was not learnt in the grade four Chinese classes. The mean number of strokes was 7.88 and the mean frequency was 9.3 per million.

Chen, Allport, and Marshall (1996) classified characters with the same number of units as "simple" for less strokes and "complex" for more strokes. In this study, Type 4, Type 5, and Type 6 were simple two-unit characters. Type 7, Type 8, and Type 9 characters were complex two-unit characters that were comprised of more strokes than simple two-unit types. In future discussions I will differentiate between the character types, using the terms "*simple two-unit*" to indicate two-unit characters with fewer stroke and "*complex two-unit*" to indicate two-unit characters with more stroke.

Type 7 characters ($C_f\_S_{2m}$), for example, "很" [/han2/, very], were familiar characters with a mean number of strokes of 11.88. The mean frequency of Type 7 was 971.1 per million. Type 8 characters ($C_{uf}\_R_f\_S_{2m}$), for example, "聒" [/kut3/, noisy], were unfamiliar characters with two familiar radicals. The mean number of strokes and the mean frequency of this type were 11.86 and 7.5 per million, respectively. Type 9 characters ($C_{uf}\_R_{uf}\_S_{2m}$), for example, "蚺" [/jim4/, boa], were unfamiliar two-unit characters with unfamiliar radicals. The mean number of stokes was 11.88 and the mean frequency was 2.0 per million.

Type 10 to Type 13 characters were three-unit characters with compound radicals comprised of two subradicals. Type 10 characters ($C_f\_S_3$), such as "新" [/san1/, new], were familiar characters with the compound radicals "亲" /relative/ that were comprised of two subradicals "立" /stand/ and "木" /wood/. Type 11 characters ($C_{uf}\_R_f\_SR_f\_S_3$), such as "憬" [/ging2/, realize], were unfamiliar characters with familiar compound radicals. Type 12 characters ($C_{uf}\_R_{uf}\_SR_f\_S_3$), such as "楞" [/ling6/, blankly], were unfamiliar characters with unfamiliar compound radicals but the comprising subradicals were individually familiar. Type 13 characters ($C_{uf}\_R_{uf}\_SR_{uf}\_S_3$), such as "嵇" [/kai1/, a family name], were unfamiliar characters with unfamiliar compound radicals and where one of the comprising subradicals was unfamiliar. The mean number of strokes of the above four types were 12.3, 12.3, 12.0, and 12.0, respectively. The mean frequencies were 1040.4 per million, 2.8 per million, 1.58 per million, and 8.9 per million, respectively.

Considering that the majority of compound characters are left-right structured while the top-down structured occupies the second, the ratio of left-right compound characters in each type was higher than the top-down type in order to meet the reality of the distribution of characters with different structures. Therefore, in each character type, six were selected as left-right structured and two were selected as top-down structured. Table 2 displays some examples of each character type. A complete copy of the experimental materials is attached in Appendix I.

Table 2

Characteristics and examples of each character type

Character Type (Abbreviation [1])	Number of unit	Mean number of strokes	Character familiarity	Radical familiarity	Subradical familiarity	Mean frequency [2]	Examples
Type 1 (SP)	1	7.50	--	--	--	--	
Type 2 (C_f_S_1)	1	7.63	F	--	--	1631.1	弟、年
Type 3 (C_{uf}_S_1)	1	7.88	UF	--	--	29.8	戉、禹
Type 4 (C_f_S_2)	2	7.88	F	F	--	2424.8	和、玩

Table continues

Table 2. (continued)

Character Type (Abbreviation [1])	Number of unit	Mean number of strokes	Character familiarity	Radical familiarity	Subradical familiarity	Mean frequency [2]	Examples
Type 5 (C_{uf}_R_f_S_2)	2	7.75	UF	F	--	17.2	俚、怦
Type 6 (C_{uf}_R_{uf}_S_2)	2	7.88	UF	UF	--	9.3	炯、卸
Type 7 (C_f_S_{2m})	2	11.88	F	F	--	971	很、期
Type 8 (C_{uf}_R_f_S_{2m})	2	11.88	UF	F	--	7.5	聒、酌
Type 9 (C_{uf}_R_{uf}_S_{2m})	2	11.88	UF	UF	--	2.0	踐、蚺
Type 10 (Cf_S3)	3	12.25	F	F	F	1040.8	新、蜂
Type 11 (C_{uf}_R_f_SR_f_S_3)	3	12.25	UF	F	F	2.8	憬、喋
Type 12 (C_{uf}_R_{uf}_SR_f_S_3)	3	12.00	UF	UF	F	1.6	楞、愰
Type 13 (C_{uf}_R_{uf}_SR_{uf}_S_3)	3	12.00	UF	UF	UF	8.9	嵇、嗑

Note. [1] Explanations of Abbreviations: C—character; R—radical; SR—subradical; S—structure; F/$_f$—familiar; UF/$_{uf}$—unfamiliar; $_1$—single-unit character; $_2$—two-unit character; $_3$—three-unit character; $_m$—more strokes / complex two-unit.

[2] Bei, G. Q., & Zhang, X. T. (1988), mean frequency per million.

3.3 Procedure

This study selected the delayed-copying Task as the measuring method of children's visual chunking skills. The difference between this study and previous studies was that the period of exposure to the stimuli was computer controlled to elicit a more precise timing than can be achieved through manual methods(Ku, Anderson, Li, Wu, & Hao, 2002; Pak, et al., 2005; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003). The size of stimuli was 550 set in Microsoft PowerPoint with Regular font (標楷體). The order of the stimuli was randomized into two versions to control the *order effect*. For the fourth grade, two versions were provided. Half of the students were given version one and the other half received version two. For the first and the second graders, consideration was given to the potential negative effect of time limitations on their performance. It was therefore decided to conduct the experiment in two sessions. Thus, four versions were provided for the first and the second graders. For the first and the second grades, the 104 stimuli were divided into two 52-stimuli sections (A and B). The presenting order of the stimuli in each section was further randomized into two versions (A1, A2, and B1, B2) by blocks reverse counterbalancing. Each child received one of the combinations (A1B1, A1B2, A2B1, and A2B2) in the two experiments. The two 52-stimuli sections were administrated within two weeks for the first and the second graders. The experiment lasted about 35 minutes for the fourth grade and approximately 45 minutes in total for the first and the second grades.

The experiment was administered at the end of school year in small-groups comprising a maximum of 23 subjects. Seats were arranged to make sure that every child could see the stimuli clearly. A trained psychology graduate student conducted the experiment, assisted by another trained psychology undergraduate (She was taught how to instruct children to correctly respond the task), who made sure every child responded correctly. Masking technology was used. A visual symbol "+" in the middle of the screen and a "ding" sound were presented simultaneously just before the presentation of each stimulus in order to draw the children's attention to the screen. As the capacity of short-term memory (STM) reflects the quantity of items that people are able to process within two seconds, each stimulus was presented for two seconds. The writing task was to trace each stimulus and reproduce it. Children were not allowed to write until the stimuli vanished. Enough time was allowed for every child to finish copying, but the children were not allowed to see what their peers were writing. The children received the first five items for practice to make sure they understood the task. A one-minute break was given in the middle of the experiment.

3.4 Statistical Analysis

One character in Type C_{uf}_R_f_S_{2m} was discarded in data analysis because it was found to be inconsistent with other characters in radical position frequency. Thus, only 95 characters and 8 stroke-patterns were included in data analysis. Two trained undergraduate students rated the children's response in the delayed-copying task. The researcher triple-checked all the ratings.

Mean rating of the neatness of handwriting was collected to conduct correlation with children's performance in the delayed-copying task. It was possible that the neatness of the children's handwriting influenced the coding of their performance in reproducing characters. Three raters (the children's class teacher and two independent raters who were blinded to the children's literacy and performance) were asked to rate the degree of the neatness of children's handwriting. The rating criteria included the clarity of writing and the ratio of length of different strokes. Instruction was given to the raters. The score range was set incrementally from score one to score five, with score one representing the most untidy (i.e. poorest) handwriting and score five representing the neatest handwriting. The neatness of handwriting was correlated with the mean performance to investigate any possible relationship between neatness of handwriting and mean performance.

The main statistical analysis was divided into two parts: a) accuracy analysis, and b) error analysis. The accuracy analysis concerned the percentages of responses that were correct in each grid; the error analyses concerned the percentages of different types of reproduction error that were made by the children. For all statistical tests, an alpha level of .05 was used.

3.4.1 Accuracy analyses

The Neatness of Handwriting. A correlation was conducted between children's performance in the delayed-copying task and the neatness of handwriting to test whether the neatness of handwriting influenced the coding of the performance in this task. It was proposed that if the correlation was not significant, the coding of children's performance in the delayed-copying task was not influenced by their handwriting.

The accuracy analysis included two main examinations.

1) Visual skills in character processing. Two sub-analyses were included to explore the role of visual skills in orthographic processing in the delayed-copying task.

a) Comparison between Type 1 (SP, arbitrary stroke-pattern) and Type 3 ($C_{uf}\_S_1$, unfamiliar single-unit character): the two types were matched in the number of strokes and both types are unfamiliar stimuli that could not be further divided.

b) Factor analysis. The purpose of factor analysis was to learn to how important visual skills accounted for the variance in performance on all types in the delayed-copying task.

2) <u>The levels of chunking skills.</u> The analysis aimed to test whether children were able to use familiar chunks in character processing and to explore the level of the chunking skills that children developed in different school ages and in different levels of literacy. Three sub-analyses were included and the data of the three sub-analyses were re-grouped for analysis.

a) character-chunk. Four familiar character types were included: Type $C_f\_S_1$, Type $C_f\_S_2$, Type $C_f\_S_{2m}$, and Type $C_f\_S_3$. It was proposed that the performance should be similar among the four familiar character types if the whole characters were utilized as processing unit.

b) radical-chunk. This comparison was between the means of two-unit characters with different familiarity and the means of unfamiliar two-unit characters with radicals with different familiarity. The mean of the percentage of the performance in Type $C_f\_S_2$, $C_f\_S_{2m}$, and $C_f\_S_3$ was calculated to act as the familiar character type. The group of unfamiliar characters with familiar radicals included Type $C_{uf}\_R_f\_S_2$, Type $C_{uf}\_R_f\_S_{2m}$, and Type $C_{uf}\_R_f\_SR_f\_S_3$. The mean of the percentage of the performance in Type $C_{uf}\_R_{uf}\_S_2$, Type $C_{uf}\_R_{uf}\_S_{2m}$, and Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_3$ acted as the group of unfamiliar characters with unfamiliar radicals. The number of strokes and the number of radicals were controlled within materials. It was proposed that children were able to use familiar radical-chunks in character processing if they performed equally in familiar character type and in unfamiliar characters with familiar radical type, and that they were not able to give a similar performance in the unfamiliar character type with unfamiliar radicals.

c) *subradical-chunk*. Three unfamiliar character types of three-unit characters were included: Type $C_{uf}\_R_{f}\_SR_{f}\_S_{3}$ (with familiar radical) with mean character frequency of 2.8 per million, Type $C_{uf}\_R_{uf}\_SR_{f}\_S_{3}$ (with unfamiliar radical and familiar subradicals) with mean character frequency of 1.9 per million, and Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_{3}$ (with unfamiliar radical and subradicals) with mean character frequency of 8.9 per million. It was proposed that if the performance in Type $C_{uf}\_R_{f}\_SR_{f}\_S_{3}$ and in Type $C_{uf}\_R_{uf}\_SR_{f}\_S_{3}$ was close, and the performance was better than that in Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_{3}$, children were able to use familiar subradicals in character processing.

In each sub-analysis, descriptive statistics and Figures of the data set were identified, then an overall $3 \times 3 \times X$ (Grade $\times$ Ability $\times$ Character Type) repeated measures analysis of variance (ANOVA) was performed to test the main effects of and interactions between grade, literacy, and character type. Post hoc tests were conducted to compare the differences between each of the two grades and between high and low literacy groups; independent t-test was employed to test the differences between the SLD group and the other two literacy groups, respectively. In case of significant interaction between the variables, simple effect analysis was conducted to test the patterns of difference.

3.4.2 Error analysis

Errors identified in the task offer us a great deal of information about the features of character processing. The use of chunking strategies, and the levels of chunks used in character perception could be observed from the task errors. Shu et al. (2003) analyzed the errors identified in the copying task and categorized them into three types: *stroke-related*, *precise radicals*, and *not precise radicals*. The stroke-related error indicated that children wrote part of the target character with an unfinished radical, or only with some random strokes. Many of the errors found in this study were of the mixing types, where part of the reproduction was correct and part was incorrect. The errors were categorized into three main types in order to have the characteristics of chunking skills. The error types were: a) random-stroke error, b) radical-related error, and c) inaccurate-radical error.

a) random-stroke error was defined as the error type where only two or three strokes were accurately reproduced in the correct position, or where the radical was not finished. For example, the character “赦” was only reproduced as “土 ”. The random-stroke errors depended on all character types. This error type was regarded as the lowest level of chunk that children could not chunk strokes into component.

b) radical-related errors were counted according to characters with different number of units. In two-unit characters, radical-related errors refers to the error type where either the semantic radical or phonetic radicals of were correctly reproduced. For example, the character “赦” was reproduced as “赤 ” or “攵”.

In three-unit characters (Type 10 to Type 13), radical-related error refers to the errors that the radical or subradical were deleted or substituted. Four subtypes were found: radical substitution, radical deletion, subradical substitution, and subradical deletion. For example, the character “腥” was reproduced only as “惺”, “月 ”, or “ 星”. The first one was a case of substitution in radical level; the second and third ones were cases of deletion in radical levels. In other circumstance, “腥” was reproduced as “脂” where the subradical “曰” was replaced by another subradical “匕”, which was substitution error in subradical level. When “腥” was reproduced as “月曰 ”, “月生 ”, “ 曰”, or “ 生”, where one of the subradical was missing in the reproduction, that were deletion error in subradical level. The error analysis based on three-unit characters aimed to discuss the size of visual imagery chunks that children utilized in the delayed-copying task. The error types were further illustrated in Table 3.

c) inaccurate-radical error referred to the error type that the radical or subradical of the character was mistakenly reproduced with incorrect radicals. For example, the character “釉” was reproduced as “釉” in which one drop of the right part “釆”was missing and made a plausible radical.

Table 3

Reproduction error types in different chunking levels in three-unit character types

Level	Error Type: Substitution	Error Type: Deletion
Radical	“腥” → “惺”	“腥” → “月 ”, “ 星”
Sub_radical	“腥” → “脂”	“腥” → “月曰” or “月生” “腥” → “ 曰” or “ 生”

This part of the error analysis aimed to discuss the quality of visual imagery chunks of children. Other errors that could not be categorized into the types above (for example, drawing meaningless lines) were categorized as “Other”, and were not analyzed in this study. Table 4 (in Appendix III) summarizes the analyses conducted in the present study and the relative stimuli types involved in different analyses.

Chapter 4
Results

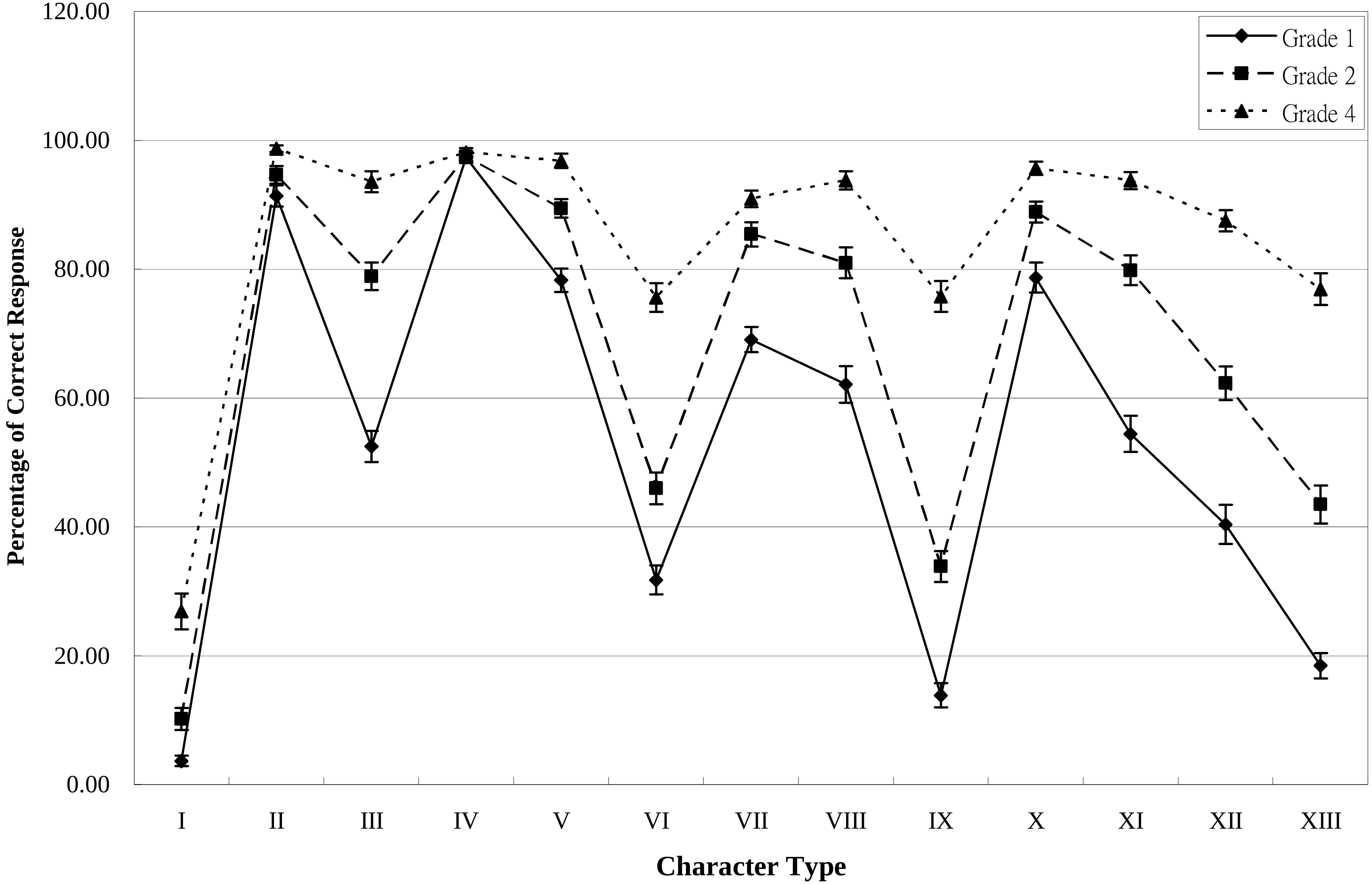
4.1 Accuracy Analysis

4.1.1 Correlation between neatness of handwriting and performance

The correlation between the neatness of handwriting rating and performance in the delayed-copying task was measured. Analysis was conducted between the mean rating scores and the mean scores of children's performance in the delayed-copying task. The results showed a small and not significant ($r=.19$, $p > .05$) correlation between the neatness of children's handwriting rating and their performances in the delayed-copying task was. This demonstrated that the rating of children's handwriting had little correlation with their performances in the delayed-copying task. The assessment of the performance in the delayed-copying task was relatively independent from children's handwriting skills.

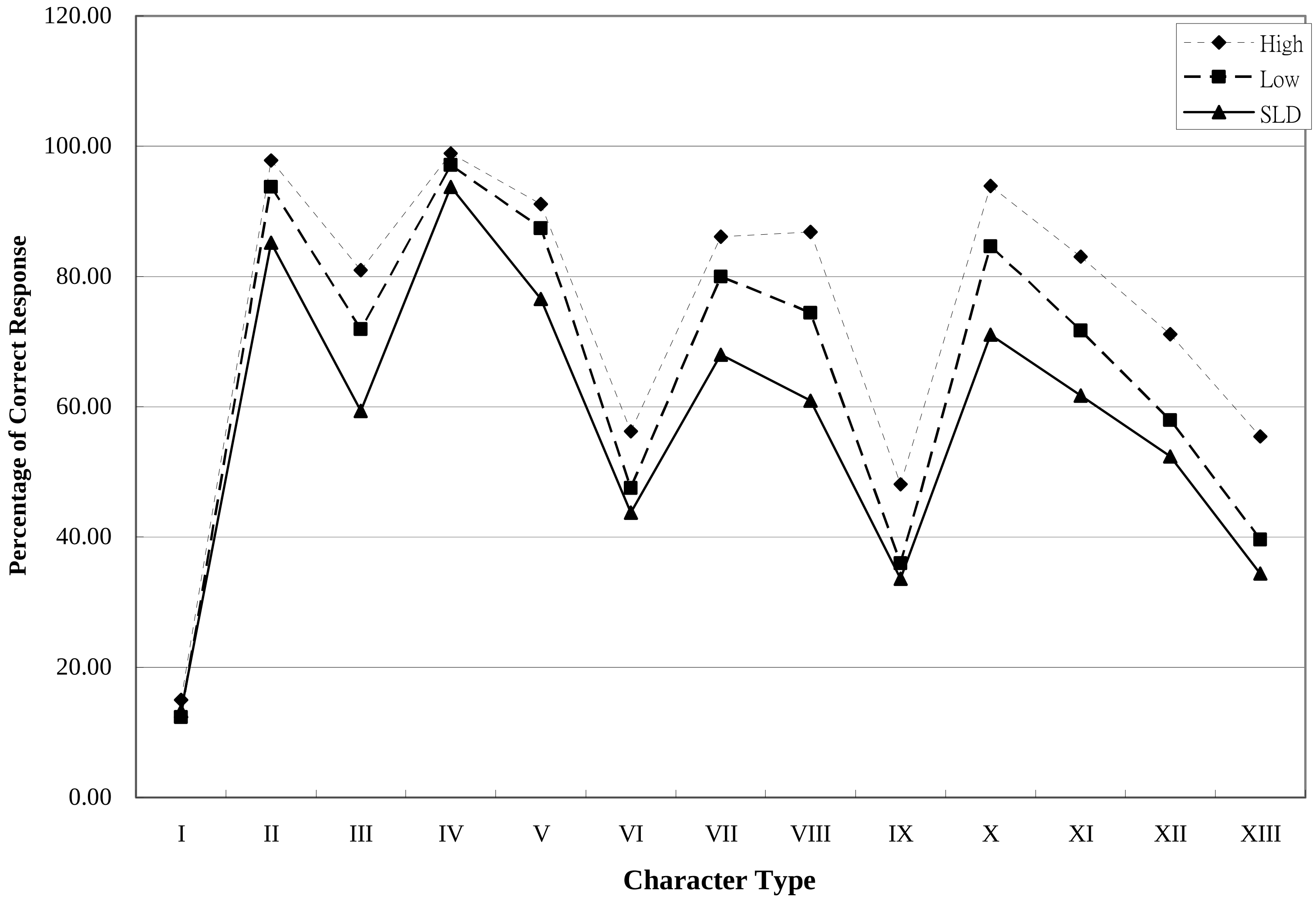
4.1.2 Overall descriptive statistics

In terms of accuracy, performances of each character type are illustrated in Figure 3 as the function of Grade and character Type, and in Figure 4 as the function of Literacy and character Type. The means and standard deviations are shown in Table 4 (See Appendix III) as the function of Grade, Literacy and character type. Generally, the fourth graders performed better than the second graders and the second graders performed better than the first graders. Children with a high level of literacy (HL) performed better than children with a low level of literacy (LL); meanwhile, the latter performed better than the children with Special Learning Difficulties (SLD). However, children with SLD were found to occasionally perform better than LL-children. The second grade children with



Note. Bars show standard error of means

Figure 3. Performance in each character type on the function of Grade



Note. Bars show standard error of means

Figure 4. Performance in each character type on the function of Literacy

SLD performed better than children with high and low literacy in the arbitrary stroke-patterns category.

In general, the study showed that the performances of children in all character types were the best in familiar character types and the poorest in the unfamiliar character types with unfamiliar radicals. The performance improved as the *level of difficulty of the character* diminished. The *difficulty of the character* refers to radicals of the characters and characters that possess different levels of familiarity. Familiar single-unit characters possessed the lowest level of difficulty, as the frequency of familiar single-unit characters was high, enabling them to be readily processed. The degree of difficulty was medium for unfamiliar characters with familiar radicals because the familiar radicals would facilitate the processing of unfamiliar characters. Unfamiliar three-unit characters with unfamiliar radicals and subradicals possessed the highest degree of difficulty because no hints could be utilized to process the unfamiliar characters.

4.1.3 Visual skills in orthographic processing

Type SP (arbitrary stroke-patterns) and Type $C_{uf}\_S_1$ (unfamiliar single-unit characters) were selected to test visual skills in orthographic processing. The two types were matched in the number of strokes and both could not be further broken down. It was hypothesized that the processing of these two types was more dependent on visual information. The assumption was made that children of different school ages and with different levels of literacy on types SP and $C_{uf}\_S_1$ would perform similarly if the visual skills in orthographic processing did not develop with schooling, and did not differ from children with different levels of literacy. Otherwise, the performances of older children would be better than younger children and children with higher literacy levels would perform better than children with lower literacy levels.

Overall Effects

Descriptive statistics are shown in Table 6 and illustrated in Figure 5 as a function of Grade and in Figure 6 as a function of Literacy. The numbers of arbitrary stroke-patterns indicate the mean percentages of the number of strokes correctly reproduced in each arbitrary stroke-pattern. For example, five strokes were correctly reproduced in their correct positions when a child tried to reproduce an arbitrary stroke-pattern building of nine strokes; the performance percentage was 77.78%. It was found that children performed significantly better in the unfamiliar single-unit character type than they did in the stroke-pattern type.

Table 6

Descriptive statistics for the analysis of visual skills in orthographic processing

Stimuli Type	Grade			Literacy		
	1 (n=65)	2 (n=65)	4 (n=66)	High (n=90)	Low (n=90)	SLD (n=16)
Type I	3.65	10.19	26.89	15.00	12.36	13.28
(SP)	(6.53)[a]	(13.78)	(22.71)	(19.85)	(17.33)	(18.52)
Type II	52.50	78.85	93.56	80.97	71.94	59.38
(C_{uf}_S_1)	(19.54)	(17.39)	(13.38)	(21.47)	(23.87)	(28.69)

Note. [a] Numbers in brackets are SD.

ANOVAs were separately conducted by the two types. Results are displayed in Table 7. In the arbitrary stroke-pattern type, the effect of Grade was significant, $F(2, 196)=15.71$, $p < .001$. Post hoc comparisons showed that the difference between the three grades were significant, in that older children performed markedly better than younger children (all $p < .01$). The effect of Literacy was not significant, $F(2, 196)=0.66$, $p > .05$. Interaction between Grade and Literacy was significant, $F(4, 196)=3.24$, $p < .05$. Since Literacy interacted with Grade, further independent t-tests were conducted in each grade. In the fourth grade, children with a high level of literacy (HL-group) performed significantly better than children with SLD (SLD-group) ($p < .05$). Differences between the HL-group and the low level of literacy group (LL-group), and between the LL-group and the SLD-group were not significant ($p > .05$). In the second grade, the SLD-group performed significantly better than the HL-group and the LL-group ($p < .05$). The difference between the HL-group and the LL-group was not significant ($p > .05$). In the first grade, the difference between each of the two groups was significant ($p < .05$); children with a higher level of literacy performed better than children with a lower level of literacy.

In the unfamiliar single-unit character type, the effect of Grade was significant, with $F(2, 196)=62.11$, $p < .001$. Post hoc comparisons showed that the differences among the three grades were significant. The fourth graders demonstrated the best performance and the first graders demonstrated the worst performance ($p < .01$). The effect of Literacy was significant with $F(2, 196)=17.15$, $p < .001$. The differences were significant between each of the two literacy groups. Children with a higher level of literacy performed better than those with a lower level of literacy ($p < .05$).

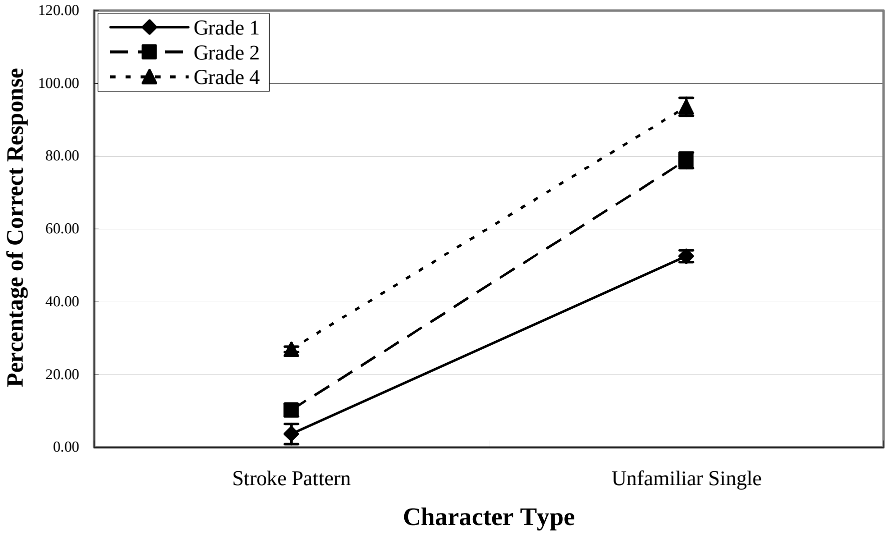
Nevertheless, the interaction between Grade and Literacy was not significant, $F(4, 196)=1.16$, $p > .05$.

Table 7

ANOVAs of accuracy analysis of visual skills in orthographic processing

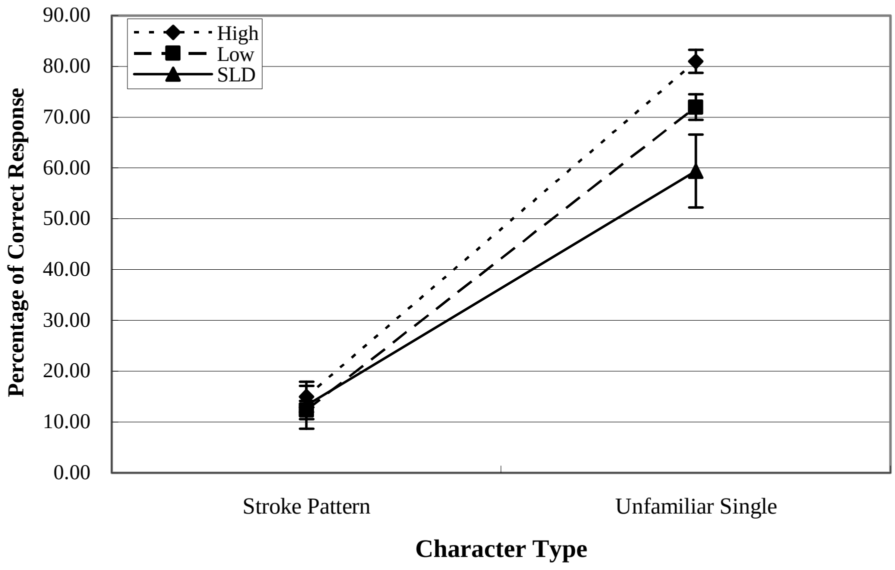
Main effect	df_1	F	p [a]
Stroke-pattern			
Grade	2, 196	15.71	.000
Ability	2, 196	0.66	.520
Grade × Ability	4, 196	3.24	.013
Unfamiliar single-unit			
Grade	2, 196	62.11	.000
Ability	2, 196	17.15	.000
Grade × Ability	4, 196	1.16	.329

Note. [a] The value of *p* listed .000 stands for $p < .001$.



Note. Bars show standard error of means

Figure 5. Percentages of correct responses of Grade 1, Grade 2, and Grade 4 subjects in delayed-copying tasks of Types SP and Type C_{uf}_S_1 characters.



Note. Bars show standard error of means

Figure 6. Percentages of correct responses of subjects with HL, LL, and SLD in delayed-copying tasks of Types SP and Type C_{uf}_S_1 characters.

Factor analysis

A factor analysis was employed to explore the effect of underlying factors influencing the delayed-copying task performance. The criterion was set at extracting one factor, *'visual skills'* as an underlying factor of the performance. The purpose was to determine to what extent visual skills accounted for the performance variance in all stimuli types in the delayed-copying task. It was found that the factor of visual skills accounted for a statistically significant 58.7% of the performance variance on all character types in the delayed-copying task.

4.1.4 Levels of chunks

Character-chunk

Four familiar character types were included: Type $C_f\_S_1$, Type $C_f\_S_2$, Type $C_f\_S_{2m}$, and Type $C_f\_S_3$. The following hypothesis was formulated: if the performance in the four familiar character types was similar, children could apply chunking skills in the level of the whole character efficiently, regardless of the differences in the number of strokes and the number of units. Descriptive statistics are shown in Table 8. A 3 × 3 × 4 (Grade × Literacy × Character Type) repeated measures ANOVA was conducted. The results are displayed in Table 9.

Overall effects.

The effect of character type was significant [$F_1(3, 561)=91.36$, $p < .001$; $F_2(3, 28)=4.47$, $p < .05$]. Children performed better in Type $C_f\_S_1$ and Type $C_f\_S_2$ than in Type $C_f\_S_{2m}$ and Type $C_f\_S_3$. The effect of Grade was significant [$F_1(2, 187)=44.15$,

$p < .001$; $F_2(2, 62)=38.23$, $p < .001$]. Post hoc comparisons showed that older children performed significantly better than younger children (all $p < .001$). The effect of Literacy was significant [$F_1(2, 187)=39.91$, $p < .001$; $F_2(2, 56)=63.11$, $p < .001$]. Post hoc comparisons showed that the HL-group performed significantly better than the LL-group ($p < .001$). Independent sample t-tests showed that both the HL and LL-groups performed better than the SLD-group (both $p < .001$).

Table 8

Means of correct percentage of the performance in familiar character types for the analysis of character-chunk

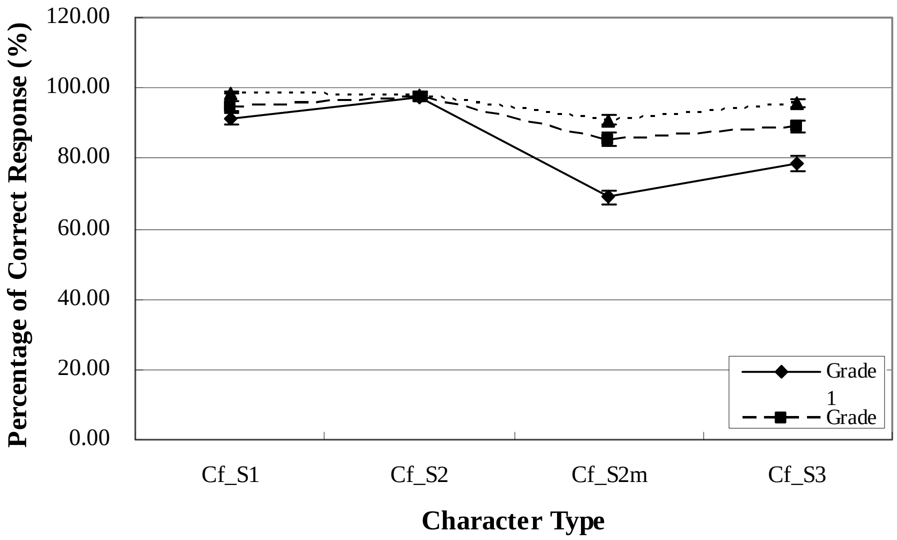
Character Type	Grade			Literacy		
	One (n=65)	Two (n=65)	Four (n=66)	High (n=90)	Low (n=90)	SLD (n=16)
$C_f\_S_1$	91.35 (13.24) [a]	94.62 (11.04)	98.67 (3.88)	97.78 (5.49)	93.75 (9.42)	85.16 (24.25)
$C_f\_S_2$	97.31 (6.81)	97.50 (5.93)	98.11 (5.02)	98.89 (4.04)	97.08 (5.94)	93.75 (11.18)
$C_f\_S_{2m}$	69.04 (15.80)	85.38 (15.08)	90.91 (10.18)	86.11 (12.91)	80.00 (17.46)	67.97 (21.88)
$C_f\_S_3$	78.65 (18.71)	88.85 (13.10)	95.64 (8.63)	93.89 (10.64)	84.58 (15.46)	71.09 (22.69)

Note. [a] Numbers in brackets are SD.

Moreover, significant interactions between the independent variables were found: Type × Grade [$F_1(6, 561)=12.28$, $p < .001$; $F_2(6, 56)=4.89$, $p < .001$], Type × Literacy [$F_1(6, 561)=6.36$, $p < .001$; $F_2(6, 56)=4.35$, $p < .01$], Grade × Ability [$F_1(4, 187)=2.68$, $p < .05$; $F_2(4, 112)=5.51$, $p < .01$]. This suggested that the patterns of the performance in the four familiar character types were different in children with different levels of literacy and in different grades.

Simple effects

Simple effect analysis was employed in each character type to find the differences between grades (See Figure 7). It was found that the Type effect was more significant in grade one [$F(3, 579)=115.68$, $p < .001$], grade two [$F(3, 579)=21.56$, $p < .001$], and grade four [$F(3, 579)=9.12$, $p < .001$].

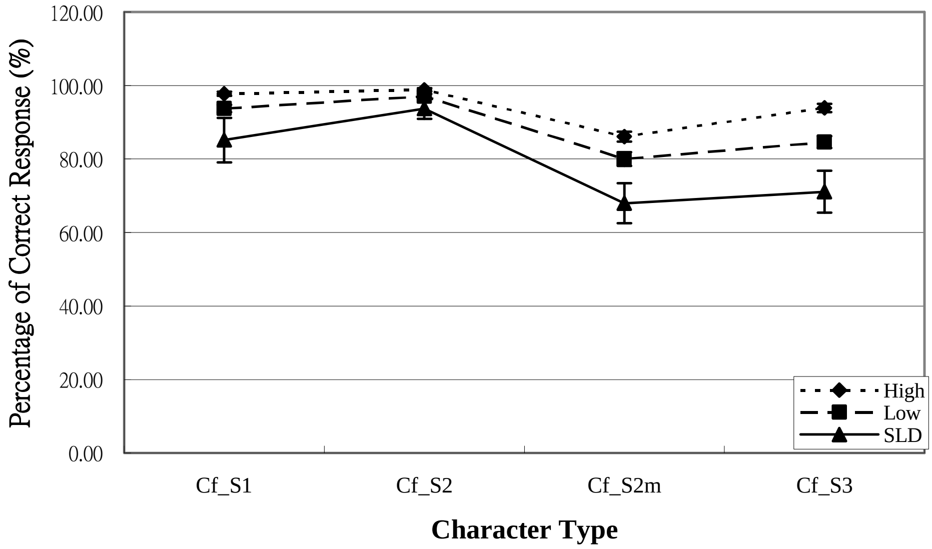


Note. Bars show standard error of means

Figure 7. Percentages of correct responses of Grade 1, Grade 2 and Grade 4 subjects in delayed-copying tasks of Types $C_f\_S_1$, $C_f\_S_2$, $C_f\_S_{2m}$, and $C_f\_S_3$ characters.

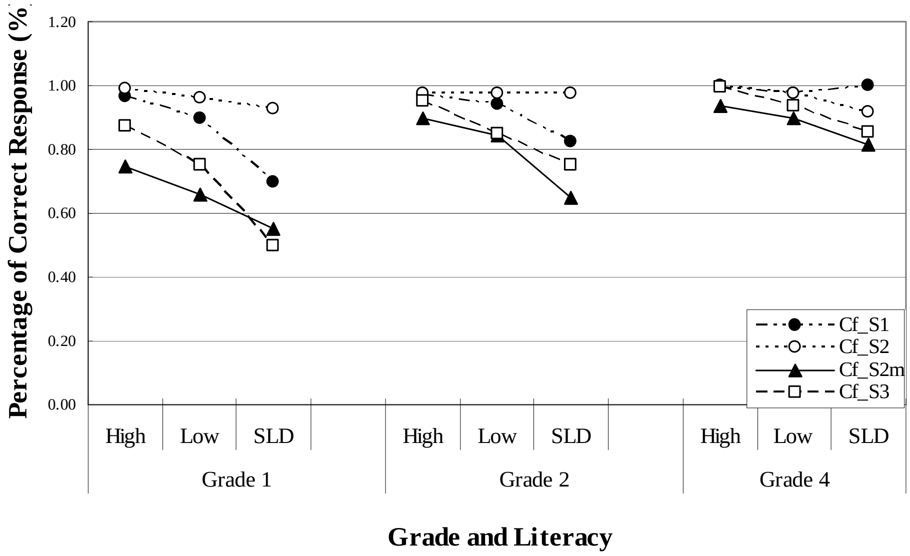
Another simple effect analysis was conducted in each literacy group to test the differences of various character types (See Figure 8). It was found that the effects of character type were all significant but similar in the three literacy groups [HL: $F(3, 579)=29.44$, $p < .001$; LL: $F(3, 579)= 55.26$, $p < .001$; and SLD: $F(3, 579)= 22.89$, $p < .001$].

Simple effect analysis was also employed in each grade by Literacy (See Figure 9). It was found that the Literacy difference was more significant in grade four: $F(2, 189)=22.38$, $p < .001$; grade two: $F(2, 189)=12.61$, $p < .001$; and grade one: $F(2, 189)=6.12$, $p < .01$.



Note. Bars show standard error of means

Figure 8. Percentages of correct responses of subjects with HL, LL, and SLD in delayed-copying tasks of Types $C_f\_S_1$, $C_f\_S_2$, $C_f\_S_{2m}$ and $C_f\_S_3$ characters.



Note. Bars show standard error of means

Figure 9. Percentages of correct responses of subjects with HL, LL, and SLD in each grade in delayed-copying tasks of Types C_f_S_1, C_f_S_2, C_f_S_{2m}, and C_f_S_3 characters.

Radical-chunk

Nine types of characters were rearranged into three groups in order to test the visual chunking skills on the radical level. Types C_f_S_2, C_f_S_{2m} and C_f_S_3 were included in the familiar character type (Type C_f). The unfamiliar characters with familiar radical type (Type C_{uf}_R_f) included Type C_{uf}_R_f_S_2, Type C_{uf}_R_f_S_{2m}, and Type C_{uf}_R_f_SR_f_S_3. The two types only differed in character familiarity. Meanwhile, Type C_{uf}_R_{uf}_S_2, Type C_{uf}_R_{uf}_S_{2m}, and Type C_{uf}_R_{uf}_SR_{uf}_S_3 formed the unfamiliar characters with unfamiliar radicals type (Type R_{uf}).

The number of strokes and the number of radicals were controlled within materials. Table 10 displays the mean scores of the performances in the three types of each grade. It was proposed that if the performance was similar in Type C_f and Type $C_{uf}\_R_f$, children could utilize radical-chunks efficiently. A smaller difference between the two types indicated better use of radical-chunks. Moreover, the performance in Type R_f and Type $C_{uf}\_R_f$ should be better than that in Type R_{uf}.

Overall effects

A 3 × 3 × 3 (Grade × Literacy × Character Type) repeated measures ANOVA was conducted. The results are displayed in Table 9. With an alpha level of .05, the main effects of all independent variables were significant - character Type [$F_1(2, 374)=778.73$, $p < .001$; $F_2(2, 69)=39.32$, $p < .001$], Grade [$F_1(2, 187)=121.69$, $p < .001$; F_2 (2, 138)=168.54, $p < .001$], and Literacy [$F_1(2, 187)=40.29$, $p < .001$; $F_2(2, 138)=125.08$, $p < .001$]. The mean of performance in Type C_f was the highest, and the lowest in Type R_{uf}. Post hoc comparisons showed that the difference between each of the two grades were significant (all $p < .001$). Older children performed significantly better than younger children. The HL-group performed significantly better than the LL-group and the SLD-group (all $p < .01$). Independent sample t-test showed that the differences between the HL-group and the SLD-group were significant in the three types (all $p < .05$); the difference between the LL-group and the SLD-group was only significant in Type $C_{F(}p < .05$), and were not found in Type $C_{uf}\_R_f$ and in Type $R_{uF(}p > .05$).

Table 10

Means of correct percentage of each regrouping character type for the analysis of radical-chunk

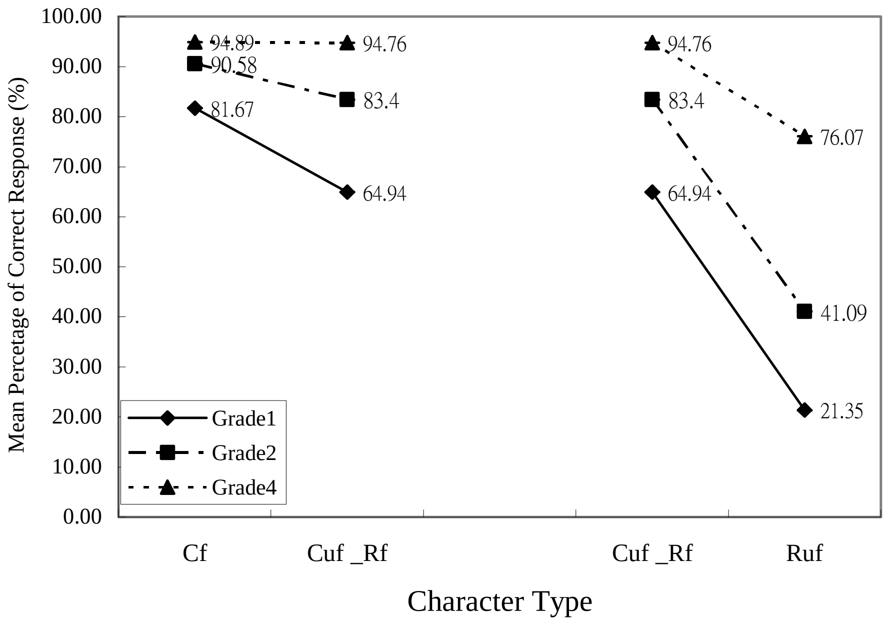
Character Type	Grade			Literacy		
	One (n=65)	Two (n=65)	Four (n=66)	High (n=90)	Low (n=90)	SLD (n=16)
C_f	81.67 (10.99) [a]	90.58 (8.50)	94.89 (5.65)	92.96 (6.83)	87.22 (10.39)	77.60 (13.77)
C_{uf}_R_f	64.94 (16.53)	83.40 (13.51)	94.76 (8.63)	86.99 (13.36)	77.82 (18.15)	66.41 (26.94)
R_{uf}	21.35 (12.34)	41.09 (17.16)	76.07 (16.12)	53.24 (27.46)	41.02 (26.14)	37.24 (25.97)

Note. [a] Numbers in brackets are SD.

In addition, significant interactions between variables were found, Type × Grade [$F_1(4, 374)=46.54$, $p < .001$; $F_2(4, 138)=19.19$, $p < .001$], and Type × Literacy [$F_1(4, 374)=4.55$, $p < .01$, $F_2(4, 138)=2.76$, $p < .01$]. Interaction between Literacy and Grade was not significant [$F_1(4, 187)=0.69$, ns; $F_2(4, 276)=4.13$, $p < .01$]. The results showed that the patterns of performance were not exactly the same in different grades and among children with different levels of literacy.

Simple effects

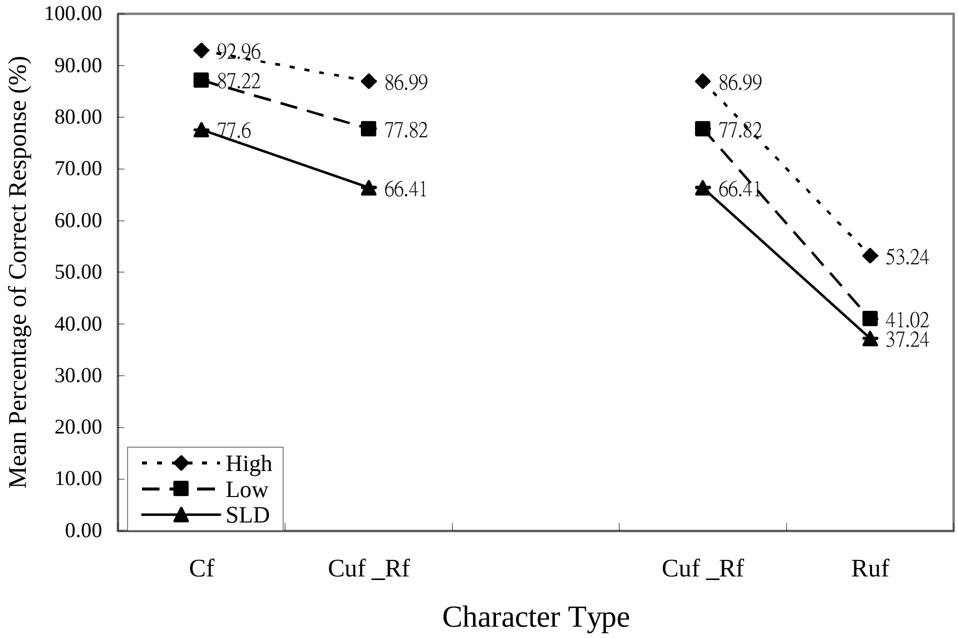
Simple effect analysis was administered to test the performance in different character types in different grades (See Figure 10). It was found that children in different grades performed more similar in Type C_f and Type C_{uf}_R_f, especially in grade four [Grade 1: $F(1, 193)=164.19$, $p < .001$; Grade 2: $F(1, 193)=30.23$, $p < .001$; Grade 4: $F(1, 193)=0.01$, $p > .05$]. The performance in Type $C_{uf}\_R_f$ was obviously better than that in Type R_{uf} in different grades, the differences were all significant in the three grades [Grade 1: $F(1, 193)=731.43$, $p < .001$; Grade 2: $F(1, 193)=689.04$, $p < .001$; Grade 4: $F(1, 193)=136.49$, $p < .001$].



Note. Bars show standard error of means

Figure10. Percentages of correct responses of Grade 1, Grade 2, and Grade 4 subjects in delayed-copying tasks of Type C_f, $C_{uf}\_R_f$, R_{uf} characters.

Further analysis was conducted to test the performance in different character types in groups with different levels of literacy (See Figure 11). It was found that children with different levels of literacy performed more similar in Type C_f and Type $C_{uf}\_R_f$ [HL: $F(1, 193)=20.81$, $p < .001$; LL: $F(1, 193)=51.54$, $p < .001$; SLD: $F(1, 193)=13.01$, $p < .001$]. The performance in Type $C_{uf}\_R_f$ was significantly better than that in Type R_{uf} in each literacy group [HL: $F(1, 193)=344.45$, $p < .001$; LL: $F(1, 193)=409.64$, $p < .001$; SLD: $F(1, 193)=45.73$, $p < .001$].



Note. Bars show standard error of means

Figure 11. Percentages of correct responses of subjects with HL, LL, and SLD in delayed-copying tasks of Type C_f, C_{uf}_R_f, R_{uf} characters.

Subradical-chunk

Three unfamiliar character types of three-unit characters were included: Type C_{uf}_R_f_SR_f_S_3 (with familiar radical and familiar subradical), Type C_{uf}_R_{uf}_SR_f_S_3 (with unfamiliar radical and familiar subradical), and Type C_{uf}_R_{uf}_SR_{uf}_S_3 (with unfamiliar radical and subradical). It was assumed that if the performance in Type C_{uf}_R_f_SR_f_S_3 and in Type C_{uf}_R_{uf}_SR_f_S_3 was similar, children could apply familiar subradical-chunks efficiently, as the subradicals of both types were familiar; smaller difference between these two types indicated better use of the subradical-chunk. Meanwhile, the performance in Type C_{uf}_R_{uf}_SR_f_S_3 should be better than that in Type C_{uf}_R_{uf}_SR_{uf}_S_3; larger difference between these two types indicated better use of the subradical-chunk. Descriptive statistics are displayed in Table 11.

Overall effect

A 3 × 3 × 3 (Grade × Literacy × Character Type) repeated measures ANOVA was administered. The results are displayed in Table 9. The main effects of the three independent variables were significant - character Type [$F_1(2, 374)=128.41$, $p < .001$; $F_2(2, 21)=7.40$, $p < .01$], Grade [$F_1(2, 187)=107.96$, $p < .001$; $F_2(2, 42)=106.81$, $p < .001$], and Literacy [$F_1(2, 187)=29.37$, $p < .001$; $F_2(2, 42)=61.01$, $p < .001$]. Children performed the best in Type C_{uf}_R_f_SR_f_S_3 and the poorest in Type C_{uf}_R_{uf}_SR_{uf}_S_3. Post hoc comparisons showed that the differences between each of the two grades were significant (all $p < .001$). Older children performed much better than younger children. The HL-group performed much better than the LL-group and the SLD-group (all $p < .01$); independent sample t-test revealed that the differences between the HL-group and the SLD-group were all significant in the three character types (all $p < .05$), which was not found between the LL-group and the SLD-group (all $p > .05$) (See Figure 13).

Interaction between Type and Grade was significant [$F_1(4, 374)=3.23$, $p < .05$; $F_2(4, 42)=0.83$, $p > .05$]. The other two interactions were not significant, Type and Ability [$F_1(4, 374)=0.77$, $p > .05$; F_2 $(4, 42)=0.33$, $p > .05$], Grade and Ability [$F_1(4, 187)=1.03$, $p > .05$; $F_2(4, 84)=2.05$, $p > .05$].

Table 11

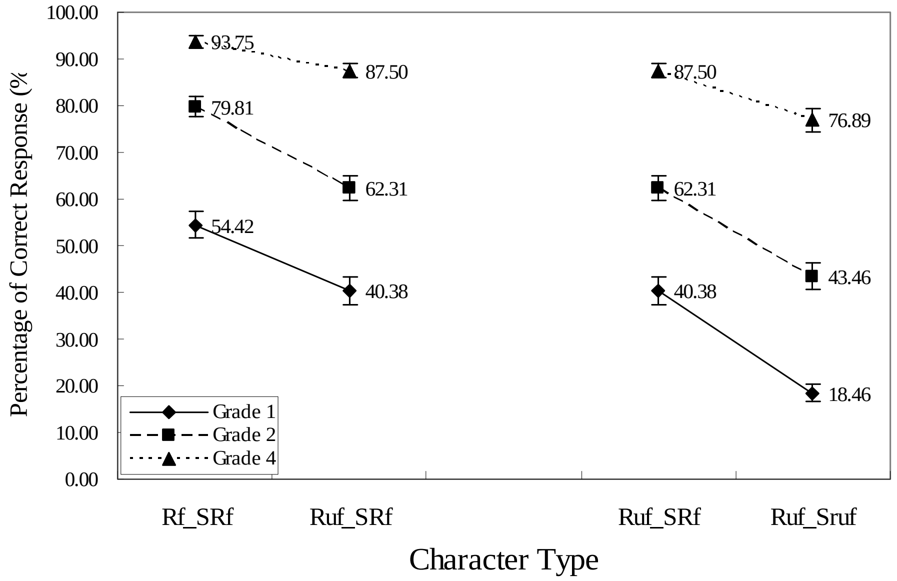
Means of correct percentage of relative character types for the analysis of subradical-chunk

Type of character	Grade			Literacy		
	One (n=65)	Two (n=65)	Four (n=66)	High (n=90)	Low (n=90)	SLD (n=16)
11	54.42	79.81	93.75	83.06	71.67	61.72
(C_{uf}_R_f_SR_f_S_3)	(22.80) [a]	(18.58)	(10.80)	(19.59)	(25.06)	(32.10)
12	40.38	62.31	87.50	71.11	57.92	52.34
(C_{uf}_R_{uf}_SR_f_S_3)	(24.28)	(21.02)	(13.16)	(23.60)	(29.24)	(31.03)
13	18.46	43.46	76.89	55.42	39.58	34.38
(C_{uf}_R_{uf}_SR_{uf}_S_3)	(15.80)	(23.60)	(19.76)	(32.19)	(28.86)	(25.21)

Note. [a] Numbers in brackets are SD.

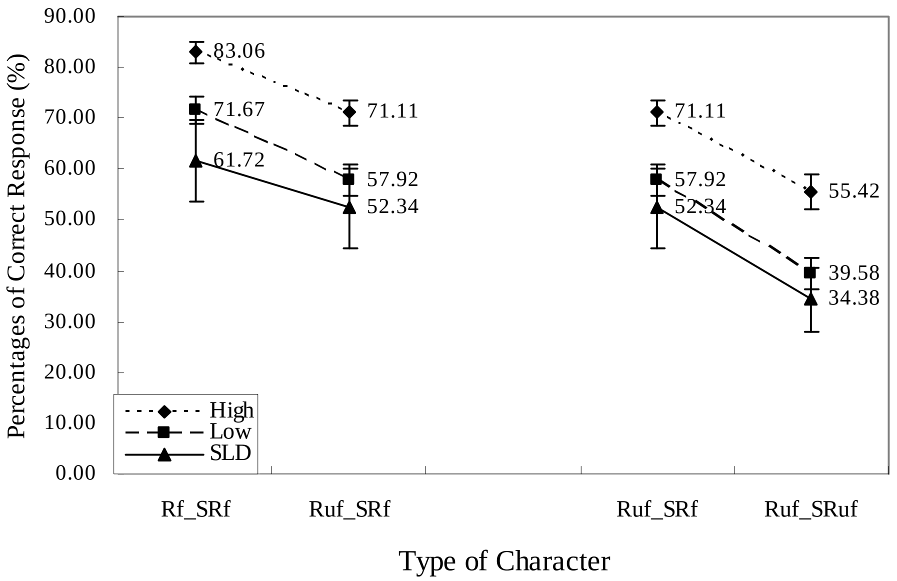
Simple effect

Further analysis was conducted for the significant interaction between character Type and Grade (See Figure 12). It was found that children in different grades performed similar in Type C_{uf}_R_f_SR_f_S_3 and Type C_{uf}_R_{uf}_SR_f_S_3. The differences were smaller in higher grades [Grade 1: $F(1, 193)=38.30$, $p < .001$; Grade 2: $F(1, 193)=59.52$, $p < .001$; Grade 4: $F(1, 193)=7.71$, $p < .001$]. The performance in Type C_{uf}_R_{uf}_SR_f_S_3 was clearly better than that in Type C_{uf}_R_{uf}_SR_{uf}_S_3 in different grades [Grade 1: $F(1, 193)=78.95$, $p < .001$; Grade 2: $F(1, 193)=58.34$, $p < .001$; Grade 4: $F(1, 193)=18.76$, $p < .001$].



Note. Bars show standard error of means

Figure 12. Percentages of correct response of Grade 1, Grade 2, and Grade 4 subjects in delayed-copying tasks of Types C_f, C_{uf}_R_f, R_{uf} characters.



Note. Bars show standard error of means

Figure 13. Percentages of correct responses of subjects with HL, LL, and SLD in delayed-copying tasks of Types C_f, C_{uf}_R_f, R_{uf} characters.

Table 9

Repeated measures ANOVAs of accuracy analysis in different levels of chunk

Main effect	df_1	F_1	p	df_2	F_2	p
Character-chunk						
Grade	2, 187	44.15	.000	2, 56	38.23	.000
Literacy	2, 187	39.91	.000	2, 56	63.11	.000
Type × Grade	6, 561	12.28	.000	6, 56	4.89	.000
Type × Literacy	6, 561	6.36	.000	6, 56	4.35	.001
Type	3, 561	91.36	.000	3, 28	4.47	.011
Grade × Literacy	4, 187	2.68	.033	4, 112	5.51	.001
Radical-chunk						
Grade	2, 187	121.69	.000	2, 138	168.54	.000
Literacy	2, 187	40.29	.000	2, 138	125.08	.000
Type × Grade	4, 374	46.54	.000	4, 138	19.19	.000
Type × Literacy	4, 374	4.55	.001	4, 138	2.76	.030
Type	2, 374	778.73	.000 a	2, 69	39.32	.000
Grade × Literacy	4, 187	0.69	.600	4, 276	4.13	.003
Subradical-chunk						
Grade	2, 187	107.96	.000	2, 42	106.81	.000
Literacy	2, 187	29.37	.000	2, 42	61.01	.000
Type × Grade	4, 374	3.23	.013	4, 42	0.83	.513
Type × Literacy	4, 374	0.77	.546	4, 42	0.33	.854
Type	2, 374	128.41	.000	2, 21	7.40	.004
Grade × Literacy	4, 187	1.03	.393	4, 84	2.05	.095

Note. The interaction among character Type × Grade × Literacy was omitted. F_1 = subject analysis; F_2 = item analysis. The value of p listed .000 stands for $p < .001$.

4.2 Error Analysis

The errors reproduced in the present study were categorized into 3 main types: 1) random-stroke error, 2) radical-related error, and 3) inaccurate-radical error. The details of the definition of error category were displayed in chapter 3. According to Shu et al. (2005) and Pak et. al (2005), random-stroke errors were considered as errors with the lowest level of visual chunking skills because the child could not chunk strokes together to form a component; radical-related errors were of higher level of visual chunking skills because it was supposed that the child recognized the target character as a whole, despite the misrecognition of one or more radicals.

The numbers of reproduction errors of each child were counted and categorized. In the analysis, it was found that the reproduction of one character might include two types of reproduction errors. For example, the reproduction of the two-unit character "釉" was reproduced as "[illegible]", in which two errors were found: one was the right part "由", which was replaced by a correct radical "月" as a radical-related error; the other one was the left part "采", which was reproduced as an incorrect-reproduction error which was an unreal, yet recognizable component. Two errors were counted in this case. As a result, the mean of the total number of errors of each subject might exceed the total number of wrongly reproduction stimuli.

4.2.1 Descriptive statistics

The total number of errors for each group are displayed in Table 12 and illustrated in Figure 14. The numbers indicate the mean total number of errors of each child. Generally, children in the lower grades made many more errors than those in the higher grades; HL-children made fewer errors than LL-children and SLD-children; LL-children made fewer errors than SLD-children.

Table 12

Total number of errors for different age groups and different literacy groups

	Grade			Literacy		
	One	Two	Four	High	Low	SLD
Total number of errors	37.81	25.30	10.60	18.39	25.93	29.00

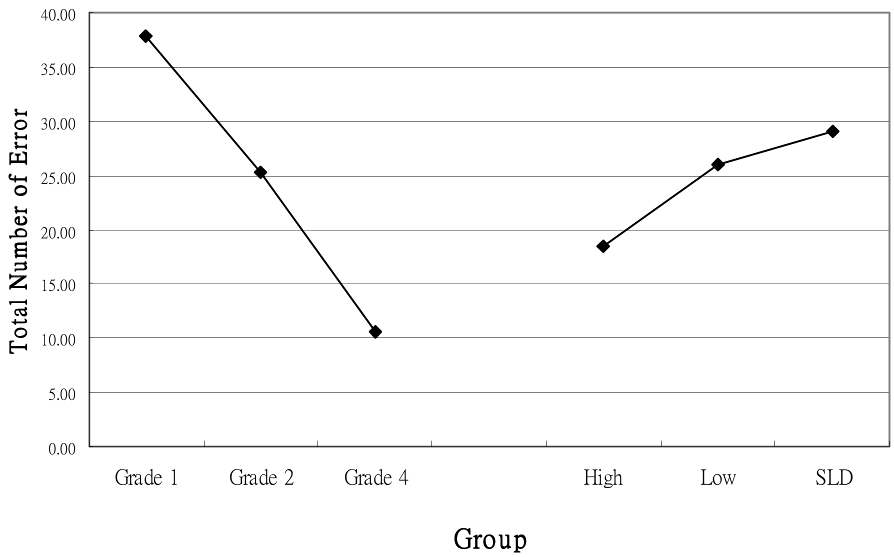


Figure 14. Total number of errors for different age groups and different literacy groups

4.2.2 Random-stroke error

Mean numbers of random-stroke errors are displayed in Table 13 and illustrated in Figure 15. The numbers indicate the mean numbers of random-stroke errors of each child in different groups.

It was clear that the first grade children made more random-stroke errors than the second and the fourth grade children; the number of random-stroke errors of the second graders was close to that of the fourth graders. This suggested that the first graders were more easily to process characters by strokes than the second and the fourth graders; and the likelihood of processing characters by strokes was low in the second and the fourth grades.

Table 13

Mean numbers of random-stroke errors of different age groups and different levels of literacy

Level of Literacy	Grade			
	One (n=65)	Two (n=65)	Four (n=66)	Total
High (n=90)	1.44	0.07	0.03	1.54
Low (n=90)	1.10	0.23	0.03	1.36
SLD (n=16)	2.48	0.20	0.33	3.01
Total	5.02	0.50	0.39	5.91

HL and LL-children made fewer random-stroke errors than SLD-children; the numbers of random-stroke errors of HL-children and LL-children were close. It became clear that grade one children with SLD made more random-stroke errors than HL-children and LL-children. The literacy difference remained in the fourth grade, that SLD-children in the fourth grade made a few more random-stroke errors than HL-children and LL-children.

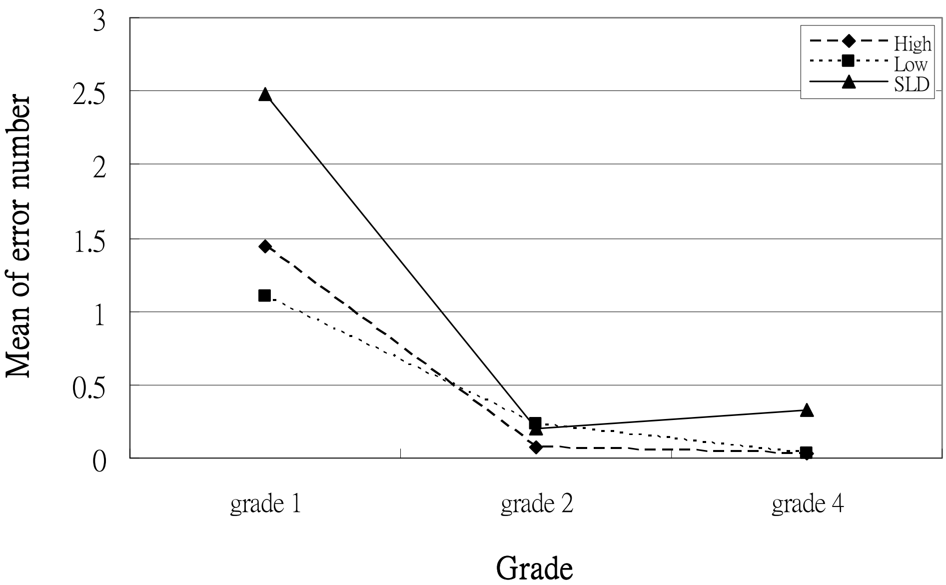


Figure 15. Mean numbers of random-stroke errors in each grade

4.2.3 Radical-related error in two–unit character types

All two-unit character types (Type 4 to Type 9) were included in this analysis. The majority of reproduction errors were found to be radical-related type in two-unit character types. Descriptive statistics are displayed in Table 14 and illustrated in Figures 16 and 17. The numbers indicate the percentages of radical-related reproduction errors in two-unit characters with different complexity.

Table 14

Percentages of radical-related reproduction errors in each group

	Grade			Literacy		
	One	Two	Four	High	Low	SLD
Error	(n=65)	(n=65)	(n=66)	(n=90)	(n=90)	(n=16)
percentage	75.92	81.58	93.20	85.08	81.07	76.37

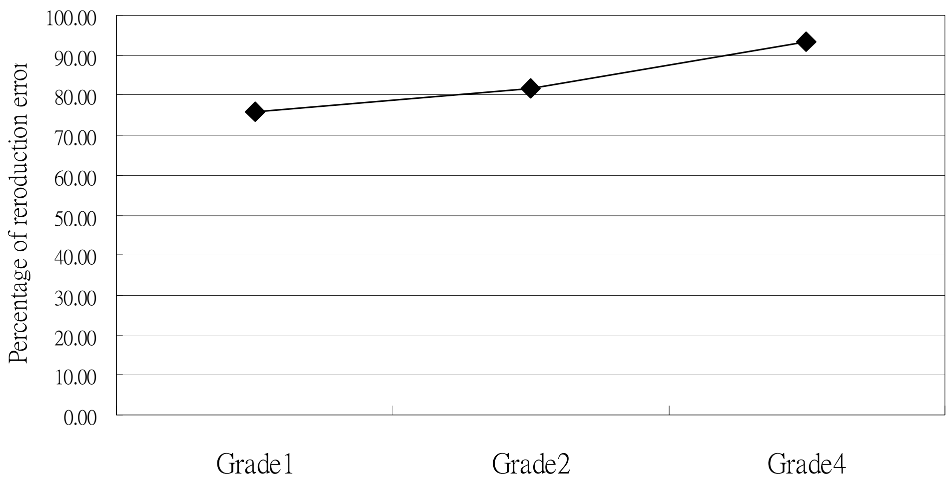


Figure 16. Percentages of radical-related reproduction errors of Grade 1, Grade 2, and Grade 4 subjects in two-unit character types.

It was found that children of higher grades made more radical-related errors than children of lower grades. The fourth graders made more radical-related errors than the second graders; the second graders made more radical-related errors than the first graders. In different literacy groups, children of HL-group made more radical-related errors than those of LL-group; children of LL-group made more radical-related errors than children of SLD-group. This suggested that the level of chunks of older children and children with a higher level of literacy were greater than their counterparts.

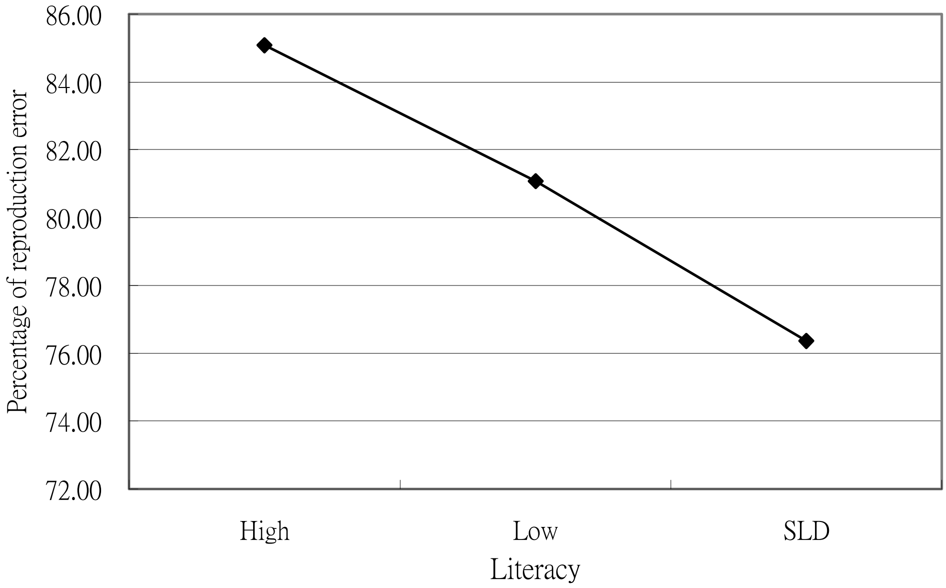


Figure 17. Percentages of radical-related reproduction errors of subjects with HL, LL, and SLD of two-unit character types.

4.2.4 Radical-related reproduction error in three-unit character types

Since the levels of chunks could be observed in the reproduction errors, three-unit characters were involved in this analysis, in order to investigate the levels of chunks utilized. Correct-reproduction errors in the reproduction of three-unit characters were analyzed according to the levels of chunks (subradical and radical) were found. These two levels of error types were further categorized according to whether the radical or subradical was deleted or substituted by other radical or subradical. The details are displayed in Table 3 in chapter 3. Descriptive statistics are shown in Table 15 and Table 16 and illustrated in Figures 18 and 19. The numbers in the tables indicate the percentages of different reproduction error types in different levels of chunks.

Table 15

Percentages of radical-related reproduction errors in three- unit character types by the function of Grade

Reproduction type	Substitution			Deletion		
Levels of chunk	Grade 1	Grade 2	Grade 4	Grade 1	Grade 2	Grade 4
Radical	0.60	0.40	0.21	1.51	1.39	0.71
Sub_radical	0.66	0.17	0.04	1.68	0.51	0.07

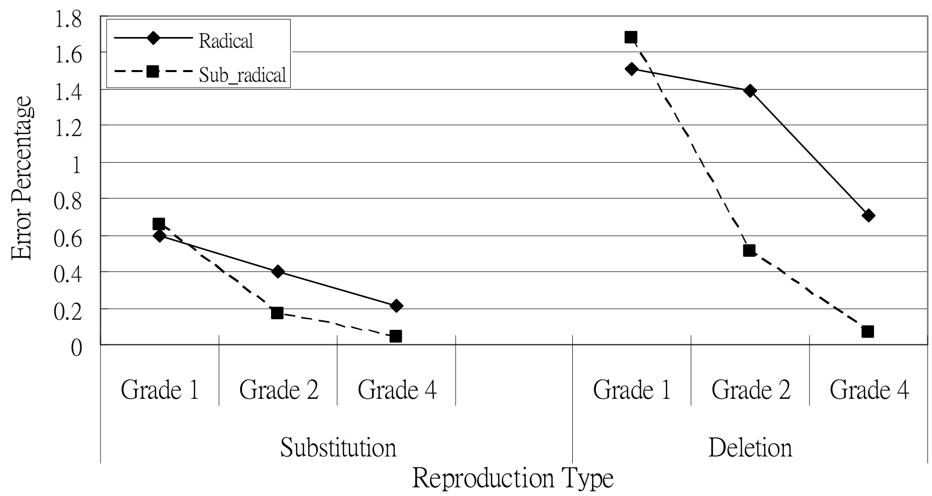


Figure 18. Percentages of radical-related reproduction errors of Grade 1, Grade2, and Grade 4 subjects of three-unit character types.

In the radical-related error analysis, it was clearly observed from Figure 18 that grade 1 student made more subradical level errors than radical level errors whatever the type of error. Grade 2 and grade 4 children made more radical level errors than subradical level errors. This suggested that children in higher grades tended to process character in a higher level than children in lower grades. Children in the fourth and the second grades processed characters in a comparatively higher level than the first grade children.

In each literacy group, children made more radical level errors than subradical level errors. Comparatively, the chance of children with SLD to make subradical level errors was larger than that of HL-children and LL-children, as the difference between the two levels of errors were smaller in SLD-children. The result suggested that the processing level of children with SLD was still in a comparatively lower level.

Table 16

Percentages of radical-related reproduction errors in three- unit character types by the function of Literacy

Reproduction type	Substitution			Deletion		
Levels of chunk	HL	LL	SLD	HL	LL	SLD
Radical	0.28	0.49	0.44	1.03	1.33	1.26
Sub_radical	0.18	0.32	0.37	0.46	0.74	1.06

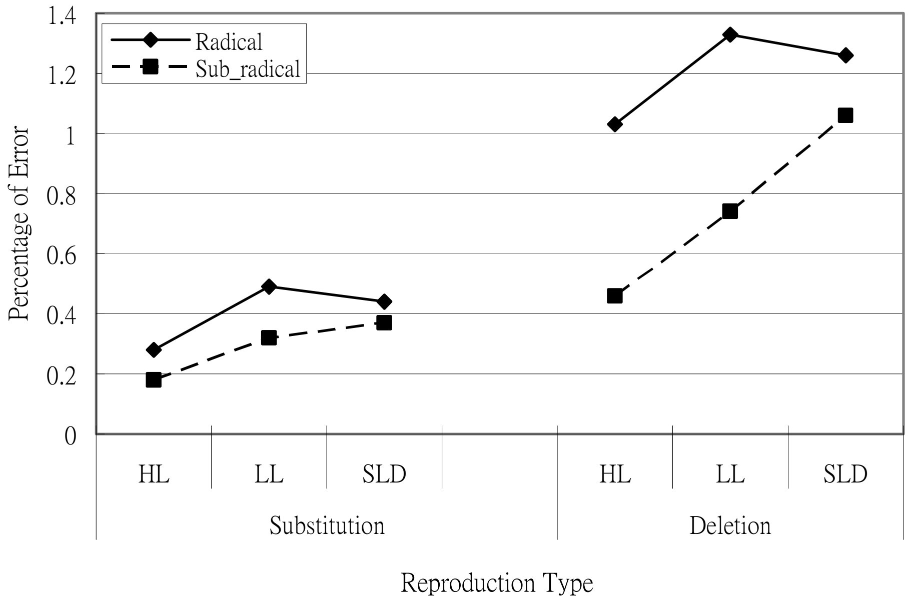
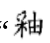


Figure 19. Percentages of correct-reproduction error types of subjects with HL, LL, and SLD of three-unit character types.

All children produced more deletion-type errors than substitution-type errors. It was suggested that the use of visual chunking skills relate to the capacity of short-term memory during limited time.

4.2.5 Inaccurate-reproduction error analysis

In inaccurate-reproduction error analysis, the reproductions were found to be replaced by unreal radicals or subradicals, where the radical or subradcial of the character was mistakenly replaced with an incorrect but plausible component. For example, the character “紬” was reproduced as “”, where a “drop” of the right part was missing, thus producing an unreal, yet recognizable component. Though children were able to separate the characters into different levels of chunks, the quality of chunks (the accuracy of chunk) differed according to children's individual stages of development or literacy levels.

Descriptive statistics of inaccurate-reproduction errors are displayed in Table 17, and illustrated in Figures 20 and Figure 21. The numbers indicate the means of the inaccurate-reproduction errors base on all character types except the type of arbitrary stroke patterns.

Table 17

The mean of the inaccurate-reproduction errors of children in grades one, two, and four

	Grade			Literacy		
	One	Two	Four	High	Low	SLD
Mean	40.87	34.18	14.20	22.79	29.76	36.71

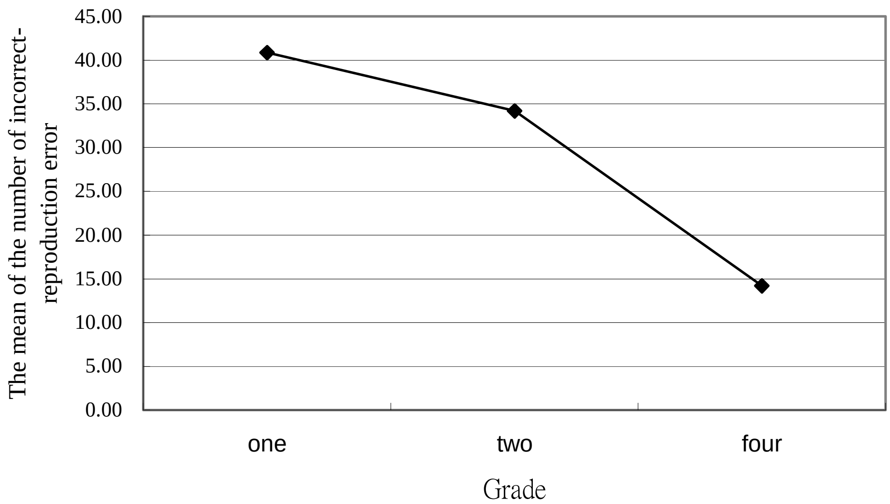


Figure 20. The mean of the inaccurate-reproduction errors of children in Grade one, Grade two, and Grade four.

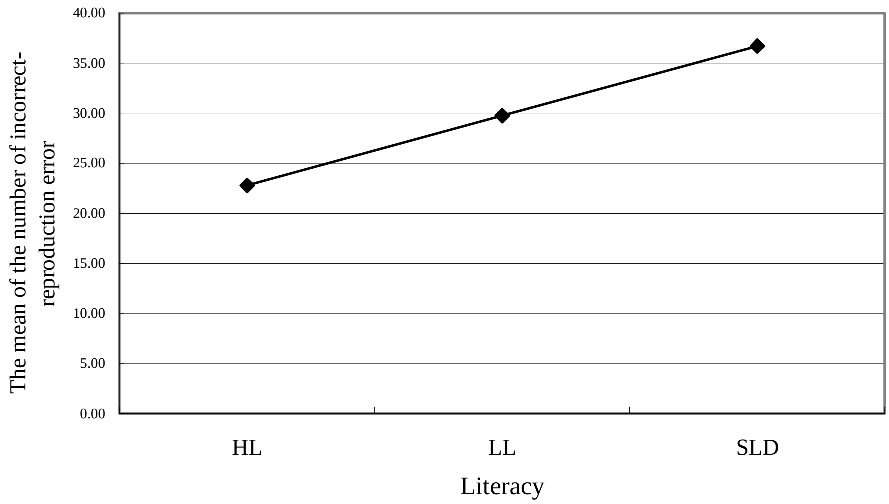


Figure 21. The mean of the inaccurate-reproduction errors of children with high literacy, low literacy, and SLD.

It was found that younger children and children with lower levels of literacy made more inaccurate-radical errors than older children and children with higher levels of literacy. This suggested that the accuracy of the chunk of older children was more precise than that of younger children; meanwhile, the accuracy of chunk children with a higher level of literacy was greater than that of children with a lower level of literacy.

Chapter 5

General Discussion

5.1 Visual skills and visual chunking skills in character processing

Visual skills in character processing

The hypothesis of the development of visual skills was clearly supported when older children performed significantly better than younger children in reproducing arbitrary stroke-patterns and unfamiliar single-unit characters. Moreover, visual skills contributed a significant 58.7% variance in the performance of delayed-copying tasks, which supports the previous findings that visual skills are important in Chinese character perception. Ku et al. (2002) used arbitrary stroke-patterns to investigate children's chunking skills. They found that children in the first semester of the first, second, and fourth grades were unable to copy arbitrary stroke configurations at all. The current study, however, was conducted at the end of school year and the performance in arbitrary stroke-patterns was relatively better than those reported by Ku and her colleagues. The use of stroke pattern as a new method to measure children's visual skills in character processing showed encouraging results. In the alphabetic system, according to Stanovich and West (1989), orthographic skills were related to print exposure. This study further shows that the visual skills in orthographic processing develop with printing exposure in Chinese, which enables older children to perform better than younger children in arbitrary stroke-patterns and unfamiliar single-unit characters.

However, the results were not convincing enough to determine whether children with a higher level of literacy possessed a higher level of visual skills than children with a lower level of literacy. In copying arbitrary stroke-patterns, the differences between literacy groups were found to be significant in the first grade and partly significant in the second grade and the fourth grade. The performance was consist with the level of literacy in the first and the fourth grades where children with a higher level of literacy performed better than children with a lower level of literacy. In contrast, children with SLD performed better than HL and LL-children in the second grade. It was concluded that the visual skills in orthographic processing were higher in children with a higher level of literacy in the first grade, but indeterminate in the second grade; the difference attenuated in the fourth grade between LL-children and SLD-children, but remained between HL-children and SLD-children. Moreover, the performance of all children was significantly better in unfamiliar single-unit characters than in meaningless stroke-patterns. Children with a higher level of literacy performed significantly better than children with a lower level of literacy in copying unfamiliar single-unit characters. The results suggest that children with a higher level of literacy derive greater benefit from meaningful chunks. It was inferred that the visual skills in orthographic processing related to orthographic awareness.

The results of this study do not support the hypothesis that children with a higher level of literacy possess more advanced visual skills than children with a lower level of literacy. It would be appropriate to conclude that children with different levels of literacy did differ in visual skills in character processing in the early period, although the difference did not continue during the subsequent development stages. Nevertheless, more experienced HL-children possessed more advanced visual skills than SLD-children. However, when the stimuli related to orthographic knowledge, children with a higher level of literacy were found to possess better visual skills than children with a lower level of literacy. This finding was partially consistent with that of Ho (1997). Ho used abstract figures to investigate the relationship between visual skills and reading achievement and concluded that visual skills were only important for beginning readers but not for more experienced readers. It might be concluded that the characteristics of materials used to explore visual skills in the two studies, in which non-character materials and character materials were adopted respectively, led to the different findings.

Development of visual chunking skills

The results of this study support the hypothesis that there is a positive relationship between children's ages and the development of visual chunking skills, i.e. the older the child, the more likely is that child to have better developed visual chunking skills. Older children consistently performed better than younger children in every character type, whatever the familiarity of chunks (characters, radicals, or subradicals). Generally, children performed better in types with familiar chunks. In the analysis of the familiar character-chunk level, older children performed noticeably better than younger children and the performance of older children in the four familiar character types was closer than that of younger children. In the analysis of the radical-chunk level, the difference between Type C_f and Type C_{uf} _R_f were smaller than that between Type C_{uf} _R_f and Type C_{uf} _R_{uf}. This suggests that all children were able to use radical-level chunk. However, older children were more efficient in applying radical-level chunk, especially fourth grade children; the performances of the fourth graders in Type C_f and Type $C_{uf}\_R_f$ was almost equal. In the analysis of subradical-chunk, the performance in Type $C_{uf}\_R_f\_SR_f\_S_3$ and Type $C_{uf}\_R_{uf}\_SR_f\_S_3$ were better than in Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_3$. The difference between Type $C_{uf}\_R_{uf}\_SR_f\_S_3$ and Type $C_{uf}\_R_{uf}\_SR_{uf}\_S_3$ was larger than that between Type $C_{uf}\_R_f\_SR_f\_S_3$ and Type $C_{uf}\_R_{uf}\_SR_f\_S_3$. The results indicated that the fourth graders were more skilful than the second and the first graders in using familiar chunks - radicals and subradicals - to process unfamiliar chunks. Therefore, because they applied chunks in different levels more efficiently, it was concluded that older children possessed more advanced visual chunking skills than younger children.

The subradical, radical and character familiarity effects were observed in every grade where children consistently performed better in the types with familiar chunks (correct percentage of types of familiar characters > types of unfamiliar characters; correct percentage of types with familiar radicals > types with unfamiliar radicals; correct percentage of types with familiar subradicals > types with unfamiliar subradicals). This suggests that children as young as the first graders were already aware of the chunks of characters and were able to apply certain strategies in character processing. This result was consistent with the findings of Ku et al. (2002) who found that some children in the first and the second grades were able to use visual chunking strategies to process characters. In addition, the present study found that HL-children in the fourth grade demonstrated consistently stable performances in the types with familiar chunks (familiar characters and unfamiliar characters with familiar radicals), suggesting that their visual chunking skills and the employment of strategies had developed commensurately with age.

The hypothesis that younger children would produce more low-level errors than older children was proved. In the error analysis, various types of correct reproduction types were found. The first graders were found to produce more random-stroke errors than the second and the fourth grade children. Older children made fewer inaccurate-reproduction errors and more radical-related reproduction errors. The fourth graders made more radical-related errors, which were considered as higher level chunks, than the second graders. The second graders made more radical-related errors than the first graders. Moreover, the percentages of inaccurate-reproduction errors were found to be higher in younger children than in older children. It was concluded that the visual imagery chunks of children in higher grades were more precise than their comparative groups. The results suggest that there is a positive relationship between children's ages and their awareness of chunks; children in higher grades have more precise orthographic chunks in mind. Consequently, their chunking skills were more sophisticated than children in the lower grades. Older children possessed more advanced chunking skills, demonstrating a correspondingly better performance. In addition, the visual chunking skills significantly contributed to children's performance in Chinese character recognition and reproduction. The results of this study are consistent with the results from previous delayed-copying studies and add to the limited figures on the development of visual chunking skills (Huang, 2001; Ku, Anderson, Li, Wu, & Hao, 2002; Pak et al., 2005; Shu, Qian, Wu, Cheng-Lai, & Tso, 2003).

Differences between different levels of literacy

All children performed significantly better in types with familiar chunks than in types with unfamiliar chunks. This suggests that children were able to use familiar chunks at different levels — familiar character, familiar radical, and familiar subradical — despite differences in the level of literacy. Children with high literacy (HL) consistently performed better than those with low literacy (LL); children with low literacy consistently performed better than children with SLD. The results indicated that children with a higher level of literacy derived greater benefit from the learning experience than those with a lower level of literacy. The literacy difference was observed in the first grade and remained in the fourth grade. In the first grade, SLD-children performed better in two-unit character type than three-unit character type; whereas, HL-children and LL-children performed better in three-unit character type. SLD-children in fourth grade performed obviously better in single-unit character type than in two-unit character types with similar number of strokes while HL-children and LL-children performed similarly in the two types. Moreover, children with SLD in the first and the fourth grades had deviation in applying character-chunk. However, the differences of the performance in the four familiar character types are similar in different literacy groups.

The performance was much better in types with familiar chunks (Type C_{uf}_R_f and Type C_{uf}_R_{uf}_SR_f_S_3) than in types with unfamiliar chunks (Type C_{uf}_R_{uf} and Type C_{uf}_R_{uf}_SR_{uf}_S_3), suggesting that children were able to use familiar radical-chunks and subradical-chunks to process novel characters. The difference between Type C_f and Type C_{uf}_R_f were similar in the three literacy groups; however, the difference were more significant between Type C_{uf}_R_f and Type C_{uf}_R_{uf}, especially in HL-group and LL-group. The result indicates SLD-children were less skilful in applying familiar radical-chunks. Moreover, the difference between HL and LL-children, and between HL and SLD-children were found noticeable in the subradical-chunk analysis; the difference between LL and SLD children was not obvious. It was concluded that HL-children possessed more sophisticated visual chunking skills and that they consistently performed better than LL-children and SLD-children. The development of visual chunking skills of SLD-children was not as advanced as that of HL-children; however, the literacy differences were not totally consistent between LL-children and SLD-children. We cannot say, conclusively, therefore, that SLD-children and LL-children possess different levels of visual chunking skills.

In error analysis, HL-children made more radical-related errors (regarded as high level chunks) than LL-children; LL-children made more radical-related errors than children with SLD. The difference in literacy levels was evident in grade one, where children with SLD made more random-stroke errors (regarded as low level chunks) than HL-children and LL-children. Though the percentages of random-stroke error of LL-children and SLD-children were similar in the second grade, children with SLD in the fourth grade still made noticeably more random-stroke errors than their peers. This result further demonstrated that the visual chunking skills of children with SLD were lower than those of HL-children and LL-children. When analyzing the accuracy of chunks, the following conclusion was drawn: although all children produced more inaccurate reproduction errors than accurate reproduction errors (radical-related errors) in both familiar and unfamiliar character types, children produced more radical-related errors in characters with familiar radicals but more inaccurate-reproduction errors in characters with unfamiliar radicals. The differences between the two error types were found to be smaller in HL-group and LL-group than in SLD-group. It was suggested that children with a higher level of literacy possessed higher orthographic awareness; consequently, they made fewer inaccurate-reproduction errors and more accurate-reproduction errors than children with SLD. It was concluded that the accuracy of visual imagery chunks for children with SLD was less precise than that of their peers. The hypothesis, that children with a higher level of literacy would make fewer low-level errors than children with a lower level of literacy, was proved between HL-children and SLD-children.

It was found in this study that the literacy difference continued into the fourth grade. The result is consistent with those of Ku et al. (2002) but not consistent with the findings of Pak et al. (2005). Ku et al. found that the copying performance in the character task had a high correlation with vocabulary and reading in the fourth grade. They concluded that those children who had not developed perceptual chunking skills in the fourth grade had serious reading problems. Pak et al. (2005) found that the difference between literacy groups decreased in the fourth grade. The current study found that the performance of children with SLD was poorer than that of their counterparts even in the fourth grade. The finding indicates that although children with SLD in grade four gained rather high scores in the delayed-copying task, they did not develop visual chunking skills as efficiently as their peers with normal literacy levels. The divergent conclusions of the three studies might be attributed to the SLD grouping adopted for the present study. In previous studies, the design of ability groups always included poor readers and good readers or average readers, while SLD-children were always assigned as poor readers or low literacy. In the present study, SLD-children were separated from low literacy children.

5.2 Relation between print exposure and the development of visual chunking skills

Both alphabetic studies and Chinese studies have shown that the development of visual chunking skills and the advancing of levels, as well as other factors, may have a close relationship with print exposure (Anderson, Wilson, & Fielding, 1988; Cipielewski & Stanovich, 1992; Cunningham & Stanovich, 1990; Ku & Anderson, 2001; McBride-Chang & Chang, 1996; Shu, Meng, and Cheng-Lai, 2003; Stanovich & West, 1989). Print exposure was defined by McBride-Chang and Chang (1996), as the extent to which children had been immersed in different sources of literature (i.e., books and magazines). In the alphabetic system, Cunningham and Stanovich (1990) used the Title Recognition Test (TRT) to evaluate print exposure. They found that the differences in word recognition competency, which were caused by variations in orthographic processing abilities, were partly influenced by the differences in print exposure. Increased reading enables older children to develop higher and more proficient chunking skills than younger children. In addition, they found that print exposure was predictive of reading ability.

Stanovich and West (1989) found that individual differences presented in reading and spelling were the result of variations in orthographic processing (OP) skills. Meanwhile, these OP skills appeared to be linked with print exposure and environmentally mediated, indicating that increased reading activity could enhance children's reading performance. Moreover, children with higher reading ability were found to engage in more out-of-school reading activities. The reading habit produced greater differences in older children (Anderson, Wilson, & Fielding, 1988). Children with greater print exposure had increased opportunity to meet new characters and radicals than children with less print exposure. This meant that children with more exposure experience might incidentally learn characters through normal reading and therefore have developed prior knowledge of unfamiliar characters or radicals (Ku & Anderson, 2001). This is the basis for the theory that good readers get better and poor readers get poorer. In a Chinese study, Ho (1997b) found that even when attempting to read in the low frequency characters that both first and second graders had not learned, the second graders performed better than the first graders in the reading task. Ho considered that low frequency characters were less familiar to the first graders than the second graders because the second graders had more radical experience. The reading experience also facilitated children's performance in processing unfamiliar stimuli.

Shu, Meng, and Cheng-Lai (2003) investigated the lexical representation and processing of Chinese-speaking poor readers. They found that poor readers had fewer automatic chunks in their orthographic representations when compared to good readers. Consequently, the response times of the online tasks (computer task) of poor readers were longer than that of good readers. She and her colleagues concluded that the connections between orthographic, phonological, and semantic skills of poor readers were relatively weak and the calculating speed was less efficient than that of good readers. According to the CMIA Model proposed by Taft and Zhu (Taft & Zhu, 1997), to recognize target characters successfully, the links between character symbols need to be strong enough to activate and spread within each other so that the matching of visual input and character symbol are accurate, prompt, and direct. Chunks of characters at different levels, such as subradicals, radicals, and high frequency characters, are often activated together. With more experience, the processing becomes more automatic as older children have practiced the links many more times than younger children; therefore, processing is more efficient in older children and children with high level of literacy. In this study, the fourth grade children with high literacy consistently gained the highest scores while the first grade children with low literacy consistently gained the lowest scores in all types. Moreover, the correct percentages were higher in types with familiar chunks while the error percentages were higher in the types with unfamiliar chunks. These results clearly demonstrated that children benefited from reading experience.

5.3 The level of chunks and the processing units

In this study, children performed the best in familiar character types; moreover, the performances were significantly better in unfamiliar character types with familiar radicals or subradicals than in the types with unfamiliar radicals or subradicals. Familiar chunks dramatically improved the performance in the perception of unfamiliar characters. The performances between the four familiar character types were smaller in children with higher literacy levels than those with lower literacy levels, especially in the fourth and the second grades. The results indicate that higher grade children with higher literacy levels benefit more from familiar character chunks. Though the fourth grade children with SLD gained rather high scores in copying familiar characters, they did not benefit from the familiar character chunks as much as HL and LL-children.

The results of this study suggest that children tend to process characters at a higher level, and provids evidence to support the assumption of the processing flow proposed in chapter two. The author proposed that the character processing followed a downward path, from top (holistic) to bottom (analytic) (Please refer to Figure 1). The processing flow explains the priority of bigger chunks. In the present study, rates of correct responses were significantly higher when the familiar chunks were at a higher level. The performance on familiar characters (largest chunk) were better than that on unfamiliar character types with familiar radicals (middle chunk); meanwhile, children performed better in the types with familiar radicals than in the types with unfamiliar radicals but with familiar subradicals (small chunk). According to Li and Chen (1999), radical chunks played a more critical role in low frequency characters. On the other hand, the recognition of characters with high frequency depended less on the analysis of radicals than it did in characters with low frequency. The results suggested that bigger chunks facilitated character perception in the delayed-copying tasks, which led to more efficient performance.

According to Guo (2000), high frequency characters were more difficult to break down than low frequency characters (Chen, 1986; Ku, Anderson, Li, Wu, & Hao, 2002; Li & Chen, 1999; Peng & Wang, 1997). Consequently, children tended to process characters at a higher level if the chunk was familiar (e.g. a familiar character); the process would shift to a lower level (e.g. radical or subradical) if the character (radical) was not familiar. The reaction time would be prolonged if the familiar chunk was small. Therefore, the performance was influenced by the type and the size of the chunks. According to Li and Chen (1999), when processing at the higher character level was finished, the lower level units will not be processed. Guo (2000) noted that the accuracy of whole character recognition was higher and the response time was reduced. In a comparison of the performances between familiar character types and unfamiliar character types with familiar radicals, the performance in familiar character types was superior, demonstrating that whole character offers the most efficient chunks in character recognition.

Luan, Shu, and Zhang (2000) administered a dictation task to a group of the sixth grade children and found the errors made were mainly correct radicals or other characters. They concluded that character processing was always based on meaningful units: radicals and characters. The majority of the errors found in the current study are in all-or-none (the reproduction was a whole chunk or not a chunk) styles where the reproductions were either meaningful units or just reproduced one or two strokes. The main processing units were found as functional chunks—familiar radicals and subradicals that were consistent with Luan, Shu, and Zhang (2000)'s conclusion. However, according to Peng and Wang (1997), the stroke was the functional unit in character processing, especially in the processing of unfamiliar single-unit stimuli. In the present study, the first graders and SLD-children were found to produce more random-stroke errors, suggesting that stroke might be one of the processing units for beginners or those with inefficient processing skills. This indicates that the visual chunking skills in character perception were influenced by the smallest processing unit—strokes, especially for early learners and children with SLD.

5.4 Suggestions, limitations, and direction for future study

Suggestions

Based on the results of this study, the author makes the following three suggestions. First of all, reading is a complicated skill which is only obtained through years of training and continuous practice. The author suggests that those recurrent stroke-patterns and radicals that are in regular use should be frequently practiced to strengthen the links in Chinese learning. Secondly, as bigger chunks lead to better visual chunking skills, the separation of the characters need not depend on every radical or stroke in character teaching. For example, if "相" [photo] and "心" [heart] have been learnt, the character "想" [think] can simply be separated into direct radicals "相" and "心", but not in "木", "目" , and "心". The explanation of the upper part is "相" which indicates "互相" [interaction] and of the lower part is "心" which indicates "心臟" [heart]. In other words, if the separation of the character produces a meaningless compound radical that cannot be identified, the analysis should be continued until the radicals can be identified or cannot be separated. For example, the character "嬰" [baby] can be analyzed into "貝貝" [cannot be translated] and "女" [female]. The former cannot be identified. Further separation can successfully elicit three radicals “貝” [shell], “貝”, and “女” that are all identifiable. Learning efficiency should be more noticeable if the chunks are bigger. Lastly, more out-of-school reading activities are recommended. Besides character learning, reading activities are positively linked to reading performance. Children meet familiar or unfamiliar chunks through reading activities that strengthen the links of chunks through abundant practice, which enables children to process characters more efficiently. Meanwhile, children can implicitly gain orthographic awareness that improves reading performance.

Limitation of this study

In the present study, the definition of low literacy was the same as the definition of poor reader in other studies. In those studies, children who fell below a specified percentile (for instance, the twentieth percentile) in a reading test were categorized as poor readers. In this study, the low literacy group was selected from the bottom 30% according to the children’s comprehensive Chinese ability test. Meanwhile, children with SLD were also included in the same range. The comprehensive Chinese ability of some low ability children was found to be even lower than children with SLD. The grouping method implicitly raised the possibility that the two groups own similar characteristics. A Chinese study by Meng et al. (2001) explored the individual differences of poor readers and found that approximately 50% of poor readers developed unbalanced visual perceptual skills and phonological awareness. They concluded that the poor readers (but not dyslexic) were not a convergent population. These children might have different advantages or disadvantages, so they should be grouped into different subtypes. Their findings suggested that when children with special learning difficulties (SLD) were under investigation, proper measurement for grouping and convergent subjects were important. It is known that children with SLD can be categorized into several subtypes, such as phonological deficit, orthographic deficit, and speed deficit. The observed differences of performances in the delayed-copying task may not be found if the children have no deficit in the relative aspects. For example, those with phonological deficits might not have problems in orthographic processing; while those with orthographic and naming speed difficulties might have problems in the task. Therefore, future studies directed towards investigating the difference between SLD-children and low literacy children should pay attention to the criteria of subject selection. Although this study found a difference between SLD-children and a low literacy level, the results were not conclusive.

Direction of future study

Firstly, it is interesting to further investigate the difference between SLD children and low literacy children while the criteria of subject selection were under controlled.

Learning experience influences children's processing of characters (Chen & Yuen, 1991; Ho & Cheung, 1999; Ho, Ng, & Au, 2001). In their Beijing study, Shu et al. (2003) reported on children's learning of characters through the *Pinyin* method (a phonetic system). Children in Hong Kong learn traditional characters by rote; the alphabet is not used in the learning progress. Traditional characters are generally more visually complex than simplified characters. It is possible that, as a result, Hong Kong children are more orthographically sensitive and more able to remember unfamiliar and complicated characters. So secondly, further studies may explore the question of whether the visual skills and visual chunking skills of children in Hong Kong have advanced under this special learning style. Such comparison should be based on identical materials, in other words, characters should be the same in both simplified and traditional character systems in order to produce a more persuasive argument.

According to Wagner and Torgesen (1987), phonological processing requires three primary skills: phonological awareness, phonological memory, and phonological retrieval. This study infers that the orthographic processing skills have consequence with many aspects, such as orthographic awareness and visual short-term memory. In the error analysis of this study, older children made more radical-chunk reproduction errors than younger children, while younger children made more subradical-chunk reproduction errors; the possibility to make subradical-chunk reproduction errors of SLD-children were larger than that of HL-children and LL-children. The results suggest that the differences relate to the capacity of short term memory (STM) of children in different development stages and with different levels of literacy. The STM capacities of older children and children with higher levels of literacy were larger than those of younger children and children with lower levels of literacy. The visual chunking skills were influenced by the capacity of short-term memory (STM). Thus, the visual chunking skills in character processing might be closely related to visual STM. And, thirdly, further studies should be carried out to test the relation between the two variables.

5.5 Conclusion

Visual chunking skills, as well as visual skills, were found to develop with schooling. Older children possessed more advanced visual skills and chunking skills than younger children. This suggests a positive relationship between print exposure and character recognition. In addition, older children demonstrated greater chunk accuracy than younger children. Children with high literacy levels possessed better visual chunking skills than children with low literacy levels and children with special learning difficulties (SLD); the difference between low literacy children and SLD-children was the level of inconsistency. Moreover, literacy differences continued into the fourth grade. However, differences in visual skills in character processing between children with different levels of literacy were found only in the first grade. The level of chunks influenced character processing and bigger visual chunks led to more efficient character processing.

References

Anderson, J. R. (1985). *Short-term memory*. In: Cognitive Psychology and Its Implication (2nd). New York: Worth Publisher.

Anderson, R. C., Li, W. L., Ku, Y. M., Shu, H. & Wu, N. N. (2003). Use of partial information in learning to read Chinese characters. *Journal of Educational Psychology, 95*, 52-37.

Anderson, R. C., Wilson, P. T. & Fielding, L. G. (1988). Growth in reading and how children spend their time outside of school. *Reading and Research Quarterly, 23,* 285-303.

Bei, G. Q. & Zhang, X. T. (1988). *漢字頻度統計 [Statistic of Chinese character frequency]*. Beijing: Dian Zi Gong Ye press.

Cao, C. Y. & Shen, Y. (1963). The recognition of Chinese characters under tachistoscopic condition in primary school children. *Acta Psychologica Sinica, 3*, 203-231.

Chan, C. K. K. & Siegel, L. S. (2001). Phonological processing in reading Chinese among normally achieving and poor readers. *Journal of Experimental Child Psychology, 80*, 23-43.

Chang, B. R. (1993). *論漢字屬性 [The properties of Chinese characters]*. In Y. Chen (Ed): 現代漢語用字資訊分析 [Quantitative analysis of modern Chinese] (pp.33-67). Shanghai: Shanghai education press.

Chen, H. C. (1986). *Radical detection in reading Chinese characters.* In H. S. R. Kao & R. Hoosain (Ed): Linguistics, Psychology, and the Chinese Language (pp.1-10). Hong Kong: University of Hong Kong, Center of Asian Studies.

Chen, J. Y. (1999). *Word recognition during the reading of Chinese sentences: Evidence from studying the word superiority effect.* In J. Wang, A. W. Inhoff, & C. H. Chen (Ed): Reading Chinese Script: A cognitive analysis (pp239-256). New Jersey: Lawrence Erlbaum Associates publishers.

Chen, M. J. & Yuen, J. C. K. (1991). Effect of Pinyin and script type on verbal processing: Comparisons of China, Taiwan, and Hong Kong experience. *International Journal of Behavioral Development, 14,* 429-448.

Chen, Y. P. & Allport, A. (1995). Attention and lexical decomposition in Chinese word recognition: Conjunctions of form and position guide selective attention. *Visual Cognitioin, 2,* 235-268.

Chen, Y. P., Allport, D. A. & Marshall, J. C. (1996). What are the functional orthographic units in Chinese word recognition: The stroke or the stroke-pattern? *The Quarterly Journal of Experimental Psychology, 49,* 1024-1043.

Chua, F. K. (1999). Visual perception of the Chinese character: Configural or separable processing? *Psychologia, 42,* 209-221.

Cipielewski, J. & Stanovich, K. E. (1992). Predicting growth in reading ability from children's exposure to print. *Journal of Experimental Child Psychology, 54,* 74-89.

Cunningham, A. E. & Stanovich, K. E. (1990). Assessing print exposure and orthographic processing skill in children: A quick measure of reading experience. *Journal of Educational Psychology, 82,* 733-740.

Edwards, J. D. (2000). *The relationship of phonological, visual, and temporal processing to reading disabilities.* Dissertation Abstracts obtained from PsyINFO: The Sciences and Engineering. Abstract No.: 3298.

Fang, S. P. & Wu, P. C. (1989). Illusory conjunctions in the perception of Chinese characters. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 434-447.

Feldman, L. B. & Siok, W. W. T. (1997). The role of radical function in visual recognition of Chinese character. *Journal of Experiment Psychology: Learning, Memory and Cognition, 23,* 776-781.

Fu, Y. H. (1993). *漢字結構和構造成分的基礎研究 [Basic studies on the structure and radicals of Chinese character]*. In Y. Chen (Ed). 現代漢語用字資訊分析 [Quantitative analysis of modern Chinese] (pp.108-169). Shanghai: Shanghai education press.

Guo, X. C. (2000). The global precedence effect in early character recognition in Chinese. *Psychological Science, 23,* 576-580.

Hao, B., Zhang, H. & Chen, S. (1983). *Experimental Psychology*. Beijing: Peking, University press.

Ho, C. S. H. (1997). The importance of phonological awareness and verbal short-term memory to children's success in learning to read Chinese. *Psychologia, 40,* 211-219.

Ho, C. S. H. (1999). Naming-speed deficits and phonological memory deficits in Chinese developmental dyslexia. *Learning and Individual Differences, 11,* 173-186.

Ho, C. S. H. (2003). *Reading acquisition and development dyslexia in Chinese: A cognitive perspective.* In N. Goulandris (Ed): Dyslexia in different languages, cross-linguistic comparison (pp277-296). Philadelphia: Whurr publishers.

Ho, C. S. H. & Bryant, P. (1997a). Phonological skills are important in learning to read Chinese. *Developmental Psychology, 33,* 946-951.

Ho, C. S. H. & Bryant, P. (1997b). Learning to read Chinese beyond the logographic phase. *Reading Research Quarterly, 32,* 276-289.

Ho, C. S. H. & Bryant, P. (1999). Different visual skills are important in learning to read English and Chinese. *Educational and Child Psychology, 16,* 4-14.

Ho, C. S. H., Chan, D. W. O., Tsang, S. M. & Lee, S. H. (2002). The cognitive profile and multiple-deficit hypothesis in Chinese developmental dyslexia. *Developmental Psychology, 38,* 543-553.

Ho, C. S. H. & Cheung, C. K. (1999). Does training in phonological awareness skills improve Chinese dyslexia children's reading performance. *Educational Research Journal, 14,* 209-228.

Ho, C. S. H., Ng, I. H. Y. & Au, A. (2001). Learning of Putonghua helps children in Hong Kong master Modern Standard Chinese better. *Journal of Psychology in Chinese Societies, 2,* 283-301.

Huang, C. Y. (1986). *Reading and writing disorders in Chinese – Some theoretical issues.* In H. S. R. Kao, & R. Hoosain (Ed). Psychology Studies of the Chinese Language (pp.39-56). Hong Kong: Chinese Language Society of Hong Kong.

Huang, H. S. & Hanley, J. R. (1994). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition, 54,* 73-98.

Huang, H. S. & Hanley, J. R. (1997). A longitudinal study of phonological awareness, visual skills, and Chinese reading acquisition among first-graders in Taiwan. *International Journal of Behavioral Development, 20,* 249-268.

Huang, J. T. & Wang, M. Y. (1992). *From unit to gestalt: Perceptual dynamics in recognizing Chinese characters.* In H. C. Chen, & O. J. L. Tzeng (Ed): Language Processing in Chinese. Advances in psychology, 90 (pp. 3-35). England: Elsevier Science Publishers.

Huang, Y. L. (2001). *"抄寫"任務下兒童漢字識別和輸出的特點及影響因素的研究 [The characteristics and factors influencing children's recognition and reproduction of Chinese characters in a copying task]*. Bachelor thesis, Beijing Normal University.

Huang, Z. & Hu, J. Z. (1990). *漢字通論 [The comprehensive study of Chinese characters]*. Wu Han: Middle China Normal University Press.

Kang, J. S. (1993). *現代漢語形聲字形符研究 [The semantic radical of modern Chinese Phonogram]*. In Y. Chen (Ed). 現代漢語用字資訊分析[Quantitative analysis of modern Chinese] (pp.68-83). Shanghai: Shanghai education press.

Ku, Y. M. & Anderson, R. C. (2001). Chinese children's incidental learning of word meanings. *Comtemporary Educational Psychology, 26,* 249-266.

Ku, Y. M., Anderson, R. C., Li, W. L., Wu, X. C. & Hao, M. L. (2002). *Visual-orthographic chunking of Chinese characters.* Group discussion paper. University of Illinois at Urbana-Champaign.

Lau, K. Y. (2002). *Development of sub-character processing and the use of orthographical and phonological memories in learning new Chinese characters* *in primary school-aged normal readers.* Bachelor thesis, The University of Hong Kong.

Law, S. P. & Leung, M. T. (2000). Structural representations of characters in Chinese writing: Evidence from a case of acquired dysgraphia. *Psychologia, 43,* 67-83.

Leck, K. J., Weekes, B. S., Chen, M. J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese readers. *Memory and Cognition, 23,* 468-476.

Leung M. T. & Lee, A. (2002) *The Hong Kong Corpus of Primary School Chinese.* Hong Kong: Department of speech and hearing, The University of Hong Kong.

Li, H. & Chen, H. C. (1999). Radical processing in Chinese character recognition: Evidence from lexical decision. *Psychologia, 42*, 199-208.

Li, J., Fu, X. L. & Lin, Z. X. (2000). Study on the development of Chinese orthographic regularity in school children. *Acta Psychologica Sinica, 32,* 121-126.

Li. Y. & Kang, J. S. (1993). *現代漢語形聲字聲符研究 [The phonetic radical of modern Chinese Phonogram]*. In Y. Chen (Ed). 現代漢語用字資訊分析 [Quantitative analysis of modern Chinese] (pp.84-98). Shanghai: Shanghai education press.

Liang, Y. H. (1994). *Chinese children's use of orthographic information and analogy process in learning to read Chinese*. Doctoral thesis, University of Illinois at Urbana- Champaign.

Lien, Y. W. (1995). *The reality process of Chinese character: The activation of phonetic information in the phonogram.* Master Thesis, National Taiwan University, Taiwan.

Lu, W. H. (1995). *Describing Taiwanese poor readers of Chinese: Phonological processing, orthographic knowledge, working memory capacity, and visual processing.* Dissertation Abstracts International Section A: Humanities and Social Sciences, 55(12-A), 3797.

Lu, Z. Y., Wang, Q. H. & Peng, D. L. (1996). A study of processing time and comprehension of sentences in story reading. *Acta Psychologica Sinica, 28,* 431-435.

Luan, H. (2001). *The subtype of Chinese developmental dyslexia: A case study of deep dyslexia.* Bachelor thesis, Beijing Normal University.

Luan, H., Shu, H. & Zhang, D. C. (2000). *The characteristics and factors influenceing children character output under the dictation task.* Group discussion paper. Beijing normal university.

McBride-Chang, C. & Chang, L. (1996). Phonological processing skills and print exposure: Correlates of word reading in children ages 9 to 16. *Reading and Writing Quarterly: Overcoming Learning Difficulties, 12,* 385-400.

McBride-Chang, C. & Ho, C. S. H. (2000a). Naming speed and phonological awareness in Chinese children: Relations to reading skills. *Journal of Psychology in Chinese Societies, 1,* 93-108.

McBride-Chang, C. & Ho, C. S. H. (2000b). Developmental issues in Chinese children's character acquisition. *Journal of Educational Psychology, 92,* 50-55.

Meng, X. Z. (2000). *The lexical representation and processing in Chinese-speaking developmental dyslexia.* Doctoral thesis, Beijing Normal University.

Meng, X. Z., Shu, H. & Zhou, X. L. (2000). 漢字字形輸出過程中兒童的漢字結構意識 [Children's structural awareness of Chinese character in character reproduction]. *Psychology Science in China, 23,* 260-264.

Meng, X. Z., Zhou, X. L., Zeng, B., Kong, R. F. & Zhuang, J. (2001). Visual perceptual skills and reading abilities in Chinese-speaking children. *Acta Psychologia Sinica, 34,* 16-22.

Muter, V. & Snowling, M. (1997). Concurrent and longitudinal predictors of reading: The role of metalinguistic and short-term memory skills. *Reading Research Quarterly, 33,* 320-337.

Nobuko, C. (1996). *The effects of 11 orthography on 12 word recognition: A study of American and Chinese learners of Japanese.* Dissertation Abstracts obtained from PsyINFO: Humanities and Social Sciences, 56. Abstract No. 3563.

Pak, K. H. A. (2001). *Comparisons of the dictation errors made by children with reading difficulty and normally achieving children.* Unpublished Bachelor thesis, Beijing Normal University.

Pak, K. H. A. (2002). *Rapid naming: Could it be the key to dyslexia diagnosis of reading and writing in Chinese?* Unpublished coursework paper, The Hong Kong Polytechnic University.

Pak, K. H. A., Chang-Lai, A., Tso, I. F., Shu, H., Li, W. L., & Anderson, R. C. (2005). *Visual Chunking Skills of Hong Kong Children*. Reading and Writing, 18, pp. 437-454.

Peng, D. L. (1997). *漢字識別中的兩種加工 [Two processing styles in Chinese character recognition]*. In D. L. Peng, 漢語認知研究 [Research of Chinese Cognition] (pp. 105-138). Shangdong: Shandong Education press.

Peng, D. L. & Li, Y. P. (1995). *Orthographic information in the identification of Chinese characters.* Paper presented to the 7th International Conference on the Cognitive Processing of Chinese and Other Asian Languages. Chinese University of Hong Kong.

Peng, D. L. & Wang, C. M. (1997). 漢字加工的基本單元：來自筆畫數效應和部件數效應的證據 [Basic processing unit of Chinese character recognition: Evidence from the effects of the number of stroke and radical]. *Acta Psychologia Sinica, 29,* 8-16.

Pollatsek, A., Tan, L. H. & Rayner, K. (2000). The role of phonological codes in integrating information across saccadic eye movements in Chinese character identification. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 607-633.

Shu, H. (1997). *漢語兒童詞彙和閱讀獲得的研究 [The study of the lexical and reading acquisition of Chinese children]*. In D. L., Peng (Ed): 漢語認知研究 [Research of Chinese Cognition] (pp. 279-295). Shandong: Shandong Education publisher.

Shu, H. & Anderson, R. C. (1997). Role of radical awareness in the character and word acquisition of Chinese children. *Reading Research Quarterly, 32,* 78-89.

Shu, H. & Anderson, R. C. (1999). *Learning to read Chinese: The development of metalinguistic awareness.* In J. Wang, A. W. Inhoff, & C. H. Chen (Ed):

Reading Chinese script: A cognition analysis (pp.1-18). New Jersey: Lawrence Erlbaum Associates publishers.

Shu, H., Anderson, R. C. & Wu, N. N. (2000). Phonetic awareness: Knowledge of orthography-phonology relationships in the character acquisition of Chinese children. *Journal of Educational Psychology, 92,* 56-62.

Shu, H. & Meng, X. Z. (2000). A preliminary study of reading disability of Chinese speaking children—Statistical data of children with reading disability. *Applied Linguistics in Chinese, 3,* 63-69.

Shu, H., Meng, X. Z. & Cheng-Lai, A. (2003). *Lexical representation and processing in Chinese speaking poor readers.* In C. McBride-Chang & H. C. Chen: Reading (Ed) development in Chinese children (pp199-214). Westport, Conn.: Praeger.

Shu, H., Qian, Y., Wu, N. N., Cheng-Lai, A. & Tso, I. F. (2003). *The role of orthographic knowledge in acquisition of Chinese characters*. Group discussion paper.

Shu, H. & Zeng, H. M. (1996). 兒童對漢字結構中語音綫索的意識及其發展 [Children's phonological awareness and its development of the structure of Chinese character]. *Acta Psychologia, 2,* 160-165.

Siegel, L. S., Share, D. & Geva, E. (1995). *Evidence for superior orthographic skills in dyslexics. Psychological Science, 6,* 250-254.

Siok, W. W. T. & Fletcher, P. (2001). The role of phonological awareness and visual-orthographic skills in Chinese reading. *Developmental Psychology, 37,* 886-899.

So, D. & Siegel, L. S. (1997). Learning to read Chinese: Semantic, syntactic, phonological and working memory skills in normally achieving and poor readers. *Reading and Writing, 9*, 1-21.

Song, H., Zhang, H. C. & Shu, H. (1995). 字音、字形在中文閱讀中作用的發展轉換 [The development of the use of graphic code and phonetic code in Chinese reading]. *Acta Psychologica Sinica, 27,* 139 – 144.

Stanovich, K. E. & West, R. F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly, 24*, 402-433.

Sugishita, M. & Omura, K. (2001). Learning Chinese characters may improve visual recall. *Perceptual and Motor Skills, 93,* 579-594.

Taft, M. & Zhu, X. P. (1997a). Submorphemic processing in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 761-775.

Taft, M. & Zhu, X. P. (1997b). *詞彙資訊加工模型：字形、讀音、詞素 [Model of lexical processing: Orthography, phonology, and morpheme]*. In D. L., Peng (Ed), 漢語認知研究 [Research of Chinese Cognition] (pp. 85-104). Shandong: Shandong Education press.

Taft, M., Zhu, X. P. & Peng, D. L. (1999). Position specificity of radicals in Chinese character recognition. *Journal of Memory and Language, 40,* 498-519.

Takao, F., Matsuo, I., Karalyn, P. & Itaru, T. (1999). Consistency, frequency, and lexical effects in naming Japanese Kanji. *Journal of Experimental Psychology: Human, Perception, and Performance, 25,* 382-407.

Taylor, I. (2002). *Phonological awareness in Chinese reading*. In W. L., Li, J. S., Gaffney, & J. L., Packard (Eds). Chinese children's reading acquisition, Theoretical and pedagogical issues (pp. 39-58). Boston: Kluwer Academic Publishers.

The Hong Kong Test of Special Learning Difficulty (1996). Hong Kong: Education and Manpower Bureau.

Wagner, R. K. & Torgesen, J. K (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101,* 192-212.

Wang, N. (1997). *漢語字詞的結構和意義 [The structure and meaning of Chinese characters and words]*. In D. L., Peng (Ed), 漢語認知研究 [Research of Chinese Cognition] (pp. 35-64). Shandong: Shandong Education press.

Wang, N. & Zhou, X. L. (1999). *漢字[Chinese character]*. Hong Kong: Hoi Fung publisher.

Wang, S. & Wang, A. S. (1992). Cognition Psychology (pp 137-201). Beijing: Peking university press.

Wang, X. J. & Sun, C. S. (1998). 漢字材料的性質對視覺短時記憶廣度影響的實驗研究 [The effect of the features of Chinese characters on the capacity of visual short-term memory]. *Psychological Science, 2,* 146-149, 158.

Woo, E. Y. C. & Hoosain, R. (1984). Visual and auditory functions of Chinese dyslexics. *Psychologia, 27,* 164-170.

Wu, J. L. & Zheng, Z. Y. (1982). Role of vergence movement in stereoscopic depth perception of human visual system. *Acta Psychologica Sinica, 14,* 415-422.

Wu. N. N., Zhou, X. L., Shu, H. (1999). Sublexical processing in reading Chinese: A developmental study. *Language and Cognition Processes, 14,* 503-524.

Xian Dai Zhong Wen Ci Dian (1997). Hong Kong: Shang wu press.

Xin Hua dictionary (1989). Beijing: Shang wu press.

Xu, Y. D., Alexander, P. & Potter, M. C. (1999). The activation of phonology during silent Chinese word reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 838-857.

Yang, H. & Peng, D. L. (1995). *The learning and naming of Chinese characters of elementary school children.* The paper presented to the 7th International conference on the Cognitive Processing of Chinese and other Asian Languages, Hong Kong.

Yeh, S. (2000). Structure detection of Chinese characters: Visual search slope as an index of similarity between different structure characters. *Chinese journal of Psychology*, *42*, 191-216.

Yu B. & Cao H. (1992a). A cognitive research on the construction modes of Chinese characters. *Psychological Science China*, *5,* 5-10.

Yu B. & Cao H. (1992b). An investigation of the effect of stroke number on the identification of Chinese characters and a discussion of the effect of stroke frequency. *Acta Psychologica Sinica, 24*, 120-126.

Yu, B., Feng, L., Cao, H. & Li, W. (1992). Visual perception of Chinese characters: Effect of perceptual task and Chinese character attributes. *Acta Psychologica Sinica, 2*, 140-148.

Zeng, J., Zhou, X. & Yu, B. (2000). Effects of construction way and stroke number in visual perception of transforming Chinese characters. *Acta Psychologica Sinica, 32,* 204-208.

Zhang, C. F., Zhang, J. H., Chang, S. M. & Zhou, J. (1998). A study of cognitive profiles of Chinese learners' reading disability. *Acta Psychologica Sincia, 30,* 50-56.

Zhang, G. & Simon, H. A. (1985). STM capacity for Chinese words and idioms: Chunking and acoustical loop hypotheses. *Memory and Cognition, 13,* 193 – 201.

Zhang, S. L., Perfetti, C. A. & Yang, H. (1999). Whole word, frequency-general phonology in semantic processing of Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 858-875.

Zhang, W. T. & Feng, L. (1992). 關於漢字識別加工單位的研究 [A study on the processing unit in recognition of Chinese characters]. *Acta Psychologica Sinica, 4,* 379-385.

Zhou, X. L. & Marslen-Wilson, W. (1999). The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 819-837.

Zhou, X. L. & Marslen-Wilson, W. (2002). Semantic processing of phonetic radicals in reading Chinese characters. *Acta Psychologica Sinica, 34,* 1-9.

Appendix I

Materials of the experiment

Character Type	Materials
Type 1 (SP)	
Type 2 (C_f_S_1)	事免雨弟面我東年
Type 3 (C_{uf}_S_1)	戌臾柬禹羌秉赤酋
Type 4 (C_f_S_2)	作明和物玩怕空爸
Type 5 (C_{uf}_R_f_S_2)	弧抉俚咣沐怦妥忑
Type 6 (C_{uf}_R_{uf}_S_2)	坍炯怵沔卸佤宦苐
Type 7 (C_f_S_{2m})	很貌球種睡期家窗
Type 8 (C_{uf}_R_f_S_{2m})	釉蛆聒酌踵番罡甦[1]
Type 9 (C_{uf}_R_{uf}_S_{2m})	踐睫耽搛徙蚋萸喬
Type 10 (C_f_S_3)	教新得清躲蜂想節
Type 11 (C_{uf}_R_f_SR_f_S_3)	腥晤憬隋堨喋袈葩
Type 12 (C_{uf}_R_{uf}_SR_f_S_3)	彰捺愣眸幌慄渠葺
Type 13 (C_{uf}_R_{uf}_SR_{uf}_S_3)	盼嵇傻嘎婿嗑蔑瓷

Note [1]. The character was discarded due the inconsistent structure and radical position frequency.

Appendix II

Consent letter to school and parent

致　校長/家長：

事由：邀請學校參加教學研究「閱讀困難兒童漢字加工的特點」

瞭解閱讀困難兒童在中文學習中的困難與個體差異，有利於揭示漢語兒童的閱讀困難本質。教學與研究結合揭示閱讀困難的本質則是幫助閱讀困難兒童的必要條件，對有針對性地制定教學方法，幫助兒童盡可能地克服閱讀困難有著極大的促進作用。

香港理工大學 護理學院「宏利兒童學習潛能發展中心」現正進行一項研究。研究的目的是希望通過精心設計的實驗來揭示孩子的漢字認知特點，從研究結果中發現閱讀困難兒童在漢字加工和漢字學習發展上與閱讀正常兒童的差異，並望能提出一些對閱讀困難兒童有效的漢字的教與學的參考方法，對教師和家長教導有閱讀困難的孩子有所助益。

研究將在一年級、二年級和四年級進行。整個施測過程約需 40-50 分鐘。研究人員首先會請學校老師選出可能有閱讀困難的學生進行閱讀水平測試，以測定該生是否閱讀困難兒童。這些學生將不包括：新移民、因智力因素、情緒因素、不認真學習和因肌肉協調能力導致成績不如意者。

研究所得的數據將只用於群體數據分析及教學研究，不用於其他途徑，並受到保密。

我們非常希望能夠得到 貴 學校、教師、家長和學生的支援及參與，使我們的研究能夠順利進行，從而期望能為孩子們的學習提供有效的教學參考方法。

祝　教安！

黎程正家博士

宏利兒童學習潛能發展中心負責人

香港理工大學護理學院副教授

聯絡電話/傳真：2766-6313

聯絡人:Ms. Pak

香港理工大學

護理學院

「宏利兒童學習潛能發展中心」

<u>邀請學生參加教學研究「閱讀困難兒童漢字加工的特點」</u>

學 校 回 條

- 本校 願意 / 不願意（請刪去不適用者）參加此次「閱讀困難兒童漢字加工的特點」教學研究。
- 校方明白此項研究的目的，並明白個人資料將會受到保密。

學校：________________

校方負責人：________________

日後聯絡人：________________

聯絡電話：________________

回覆日期：________________

家長回條

- 本人 同意 / 不同意（請刪去不適用者）孩子（姓名）__________就讀___年___班學號___參與此次「閱讀困難兒童漢字加工的特點」教學研究。本人明白此項研究的目的，並明白個人資料將會受到保密。
-

家長簽名：________________

日　期：________________

聯絡電話：________________

Appendix III

Tables

Table 4

Types of stimuli involved in each analysis

Analysis	Types of Stimuli involved
The neatness of handwriting	
Accuracy analyses—Visual skills	Type SP and $C_{uf}\_S_1$
Factor analysis	All
Accuracy analyses—Levels of chunks	
Character-chunk	Type $C_f\_S_1$, $C_f\_S_2$, $C_f\_S_{2m}$, and $C_f\_S_3$
Radical-chunk	C_f (Type $C_f\_S_2$, $C_f\_S_{2m}$, and $C_f\_S_3$) ,
	$C_{uf}\_R_f$ (Type $C_{uf}\_R_f\_S_2$, $C_{uf}\_R_f\_S_{2m}$, and $C_{uf}\_R_f\_SR_f\_S_3$) ,
	R_{uf} (Type $C_{uf}\_R_{uf}\_S_2$, $C_{uf}\_R_{uf}\_S_{2m}$, and $C_{uf}\_R_{uf}\_SR_{uf}\_S_3$)
Subradical-chunk	Type $C_{uf}\_R_f\_SR_f\_S_3$, $C_{uf}\_R_{uf}\_SR_f\_S_3$, and $C_{uf}\_R_{uf}\_SR_{uf}\_S_3$
Error Analysis	
Random-stroke	All types
Radical-related	Two-unit types, three-unit types
Inaccurated-radical	All types

Table 5

Descriptive statistics of correct proportion in each grid

Type of Stimuli / Ability	Grade1			Grade2			Grade4		
	High(n=30)	Low(n=30)	SLD(n=5)	High(n=30)	Low(n=30)	SLD(n=5)	High(n=30)	Low(n=30)	SLD(n=6)
Mean of correct proportion									
Type 1 (SP)	5.83	2.08	0.00	9.17	8.33	27.50	30.00	26.67	12.50
Type 2 (C_f_S_1)	96.67	89.58	70.00	97.08	94.17	82.50	99.58	97.50	100.00
Type 3 (C_{uf}_S_1)	59.58	48.33	35.00	86.25	73.33	67.50	97.08	94.17	72.92
Type 4 (C_f_S_2)	99.17	96.25	92.50	97.50	97.50	97.50	100.00	97.50	91.67
Type 5 (C_{uf}_R_f_S_2)	82.50	76.25	65.00	91.67	89.58	75.00	99.17	96.25	87.50
Type 6 (C_{uf}_R_{uf}_S_2)	36.67	28.75	20.00	52.50	38.33	52.50	79.58	75.42	56.25
Type 7 (C_f_S_{2m})	74.58	65.83	55.00	90.00	84.17	65.00	93.75	90.00	81.25
Type 8 (C_{uf}_R_f_S_{2m})	74.17	54.58	35.00	87.92	76.67	65.00	98.33	92.08	79.17
Type 9 (C_{uf}_R_{uf}_S_{2m})	17.50	11.25	7.50	41.25	26.25	35.00	85.42	70.42	54.17
Type 10 (C_f_S_3)	87.08	75.00	50.00	95.00	85.00	75.00	99.58	93.75	85.42
Type 11 (C_{uf}_R_f_SR_f_S_3)	65.83	45.83	37.50	85.83	76.67	62.50	97.50	92.50	81.25
Type 12 (C_{uf}_R_{uf}_SR_f_S_3)	50.83	33.75	17.50	72.08	52.92	60.00	90.42	87.08	75.00
Type 13 (C_{uf}_R_{uf}_SR_{uf}_S_3)	24.17	14.17	10.00	54.17	33.75	37.50	87.92	70.83	52.08

Table continues

Table 5. (continued)

Type of Stimuli / Ability	Grade1			Grade2			Grade4		
	High(n=30)	Low(n=30)	SLD(n=5)	High(n=30)	Low(n=30)	SLD(n=5)	High(n=30)	Low(n=30)	SLD(n=6)
Standard Deviation (SD)									
Type 1 (SP)	7.86	4.74	0.00	12.69	11.05	24.04	25.13	20.95	13.69
Type 2 ($C_f\_S_1$)	6.51	10.93	28.78	6.30	9.70	27.39	2.28	5.09	0.00
Type 3 ($C_{uf}\_S_1$)	20.42	17.29	5.59	12.86	16.97	27.39	7.83	8.52	31.04
Type 4 ($C_f\_S_2$)	3.17	6.69	16.77	6.05	6.05	5.59	0.00	5.09	10.21
Type 5 ($C_{uf}\_R_f\_S_2$)	13.37	14.44	13.69	10.03	9.89	19.76	3.17	8.78	20.92
Type 6 ($C_{uf}\_R_{uf}\_S_2$)	19.95	15.79	11.18	16.87	16.39	37.91	15.91	17.52	18.96
Type 7 ($C_f\_S_{2m}$)	11.12	16.72	22.71	10.06	15.02	24.04	8.53	10.06	13.11
Type 8 ($C_{uf}\_R_f\_S_{2m}$)	19.68	20.10	20.54	11.60	18.20	42.76	4.32	12.05	20.41
Type 9 ($C_{uf}\_R_{uf}\_S_{2m}$)	16.93	13.67	11.18	19.46	14.81	27.10	12.75	19.28	24.58
Type 10 ($C_f\_S_3$)	13.33	16.41	26.52	9.05	14.08	8.84	2.28	9.14	14.61
Type 11 ($C_{uf}\_R_f\_SR_f\_S_3$)	19.12	20.59	26.52	15.99	16.33	31.87	5.09	8.43	25.92
Type 12 ($C_{uf}\_R_{uf}\_SR_f\_S_3$)	22.73	22.54	14.25	16.31	20.94	24.04	10.73	12.92	19.36
Type 13 ($C_{uf}\_R_{uf}\_SR_{uf}\_S_3$)	18.55	10.75	13.69	23.29	20.28	19.76	13.73	17.78	21.53