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The association between children's common Chinese stroke errors and spelling ability

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Abstract

The present study adopted an error analysis approach to examine the stroke errors committed by 43 Hong Kong Chinese children of Grades 1 and 3 from a Chinese Character Copying Task. It aimed to determine the common stroke error patterns, developmental changes and the cognitive problems implied. The different types of stroke errors and total number of correct stroke sequence were further linked to Chinese word spelling ability and associated cognitive-linguistic skills. Results revealed that wrong stroke sequence and wrong character configuration were the common stroke errors in both grades and Grade 3 students made significantly fewer errors in these two categories. Both wrong stroke sequence and wrong character configuration were found to be associated with poor visual discrimination skills and visual sequential and spatial memory. Character configuration error was a significant predictor of Chinese word spelling ability whereas correct stroke sequence only contributed significantly to Chinese word spelling performance in Grade 3. These findings suggest the significance of character configuration knowledge in Chinese spelling and its importance in facilitating the orthographic developments of structural knowledge and radical knowledge. The findings have implications for the design of an enriched curriculum to teach Chinese character so as to foster a better foundation for orthographic development as well as Chinese word spelling ability.

Keywords Chinese word spelling ability · Handwriting · Orthographic knowledge · Stroke errors · Stroke sequence

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Introduction

Handwriting experience facilitates Chinese reading and spelling abilities in children as well as Chinese second language learners (Guan, Liu, Chan, Ye, & Perfetti, 2011; Guan, Perfetti, & Meng, 2015; Yeung et al., 2011). However, writing Chinese characters is not an easy task. The Chinese writing system is made up of visually complex characters, each of them can be regarded as a morpheme (Feldman & Siok, 1997; Ho & Bryant, 1997; Lam & McBride-Chang, 2018). Spelling, in the context of Chinese, refers to the processes of forming radicals or orthographic units by combining strokes (McBride-Chang, 2004). The mastery of different types of orthographic knowledge is crucial to forming a valid character (Mann, 2000; Tan, Feng, Fox, & Gao, 2001). Based on the Model of Orthographic Knowledge Development in Chinese proposed by Ho, Yau, and Au (2003)

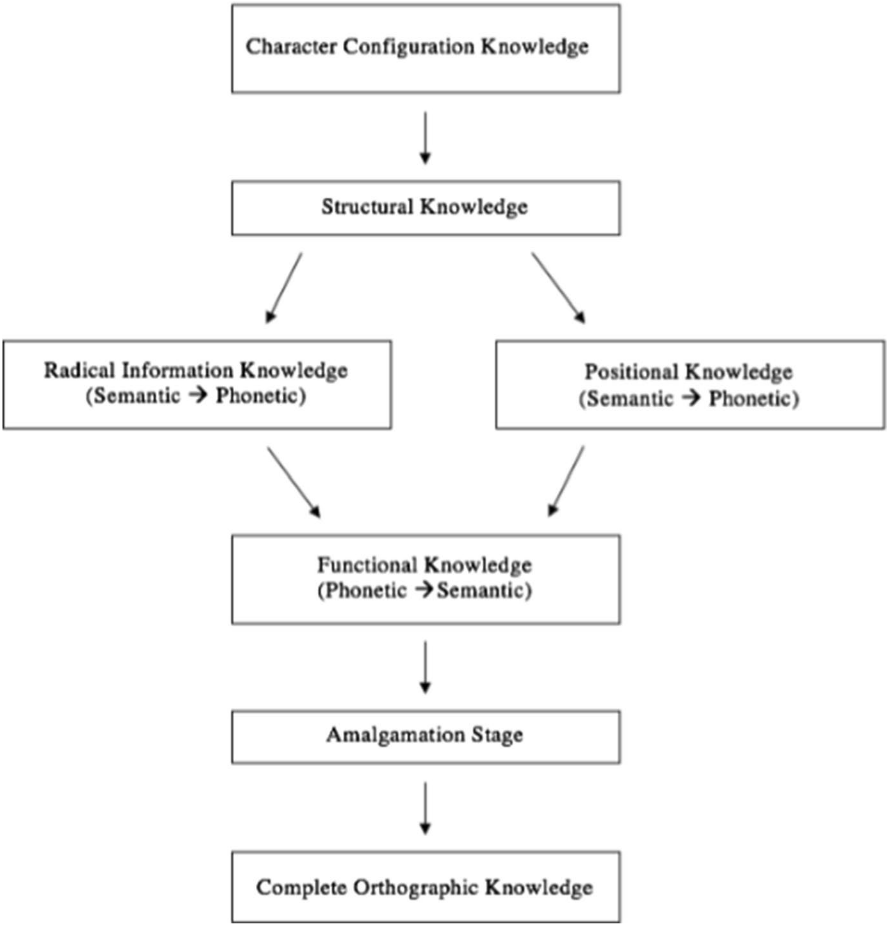


Fig. 1 A model of orthographic knowledge development in Chinese (Ho et al., 2003)

shown in Fig. 1, the development of orthographic knowledge is a sequential process with six stages. The first stage is about character configuration knowledge in which children need to be acquainted with the overall figure and structures of Chinese characters. The stage of structural knowledge puts more emphasis on the segmentation of characters into different stroke-patterns, namely stroke forms and stroke sequences. It is followed by a stage of radical information knowledge and positional knowledge where the meanings, sounds and the positional constraints of radicals are focused. In the functional knowledge stage, children start to make associations between radicals and the corresponding sounds or meanings. The amalgamation stage is for the integration of different types of orthographic knowledge to facilitate the application of knowledge to reading and spelling. Each stage serves as an important basis for the later developmental stages and a complete set of orthographic knowledge in Chinese.

The present study focuses on the structural knowledge of Chinese writing system. It aims to identify the common Chinese stroke errors made by Grade 1 and Grade 3 primary school children for finding factors contributing to Chinese spelling ability. Handwriting and spelling are two interrelated fields which lay the foundations for children's writing development (Berninger et al., 2002; Lam & McBride-Chang, 2018; Yan et al., 2012). Through examining children's stroke errors, it can facilitate the understanding of orthographic knowledge development and the independent roles of handwriting errors in Chinese spelling.

The importance of structural knowledge in Chinese writing system

Strokes

Chinese characters are arranged in square-shaped forms which can be broken down into the smallest graphic units called strokes. It is further classified into simple stroke forms and composite stroke forms (Law, Ki, Chung, Ko, & Lam, 1998). Simple stroke forms are direction strokes which can exist independently as shown in Fig. 2 while composite stroke forms are made up of more than one basic stroke (Law et al., 1998; Lo, Yeung, Ho, Chan, & Chung, 2016). Owing to different categorization schemes, there is no consensus over the number of stroke forms and it varies from 21 stroke forms to 41 stroke forms (Wang & Xu, 1993; Wen, 1964).

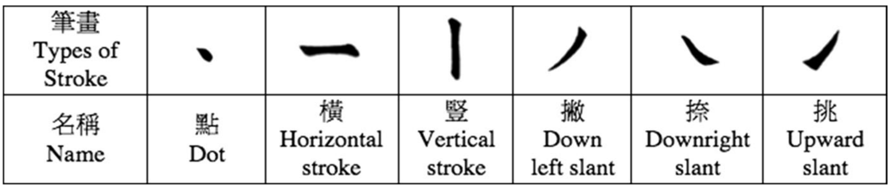


Fig. 2 The six types of basic stroke form in Chinese

Stroke is considered to be important in Chinese handwriting not only due to its long historical value, but also its unique contribution to Chinese word recognition. Peng and Wang (1997) and Zhang and Feng (1992) have shown a positive association between stroke number and processing time of a character. A character with fewer strokes was recognized faster than a character with more strokes given the same number of radicals (Peng & Wang, 1997). This implied stroke numbers could indicate the visual complexity of a character which was highly associated with the speed of processing. Stroke form is also crucial for Chinese handwriting as it provides a consistent stroke pattern for memory encoding. In the study conducted by Anderson et al. (2013), Grades 1, 2 and 4 children were required to complete a Delayed Copy Character Task. In that task, forty characters were presented to the participants one at a time for 2 s and then removed. Then, they had to write the character seen on an answer sheet. The characters chosen included the following types or features: familiar simple characters, familiar compound characters with familiar components, unfamiliar compound characters with familiar components, non-characters with familiar components and arbitrary stroke patterns. The result showed that most Grades 2 and 4 students had high accuracy in re-writing characters with familiar components, even some of them were non-characters. However, all grades children failed to reproduce arbitrary strokes patterns with no identifiable components or subcomponents of real characters. It suggested that stroke forms were necessary for children to perceive characters into meaningful chunks for visual encoding.

Stroke sequence rules

Apart from the static representation of the structure in a character, Chinese writing system also stresses on the dynamic representation of writing Chinese characters which is identified as stroke sequence (Katanoda, Yoshikawa, & Sugishita, 2001). Packed into a square-shaped configuration, the initial stroke of Chinese characters is not as clearly distinguishable as in English words (Chen, 1992; Chen, Lau, & Yung, 1993; Tan, Hoosain, & Siok, 1996). Therefore, stroke sequence rule is essential in guiding us to write Chinese characters. There are six major stroke sequence rules as listed in Table 1 (Law et al., 1998). For example, according to Rule 1, when the character has a top–bottom (上下結構) or top-middle-bottom (上中下結構) orthographic structure, it needs to be written from top to bottom. Although exceptions or inconsistency of the rules exist, complying with the rules enables writers to have a better spatial arrangement of characters. It also provides cues for the memory retrieval in Chinese character recognition and reading (Giovanni, 1994; Shimomura, 1980).

Important cognitive skills for Chinese handwriting

Visual-orthographic discrimination skill

Visual-orthographic discrimination skill, one of the major types of visual perceptual skills, is important in detecting subtle stroke differences since some of the Chinese

Table 1 Major stroke sequence rules in Chinese (Lo et al., 2016)

Rule	English version	Chinese version
1	Write from top to bottom	先上後下
2	Write from the left to the right	先左後右
3	Horizontal strokes should be written first before vertical one except that the horizontal stroke is at the bottom of a character	先橫後豎
4	Write the downward slant on the left side before the downward slant on the right side	先撇後捺
5	Write the middle component before writing the parts on either side	先中間後兩邊
6	When writing a character with a rectangular enclosed structure, write the outside except for the bottom stroke and then finish the component inside the structure and at last write the horizontal stroke to seal the enclosed structure	先裡頭後封口

characters are visually similar (Mcbride-Chang, Chow, Zhong, Burgess, & Hayward, 2005). A small difference in the position of strokes or stroke forms can change the meanings of the characters (e.g., 土,士; 太,犬). Hence, visual-orthographic discrimination skill allows children to distinguish visually among graphic forms and to judge their correctness (Søvik, 1975; Thomassen & Teulings, 1983). Moreover, based on the comparisons between typical and dyslexic children, dyslexic children had greater number of additional or missing stroke error and the poorer organization of radicals (Lam, Au, Leung, & Li-Tsang, 2011). This may be due to their delayed visual perceptual skills, especially visual-orthographic discrimination skill (Lam et al., 2011; Tseng & Murray, 1994).

Visual sequential memory

Although research postulated poor English spellers may not have an inferior visual sequential memory, a different result may be observed in non-alphabetic Chinese handwriting as it involves more visual cues like stroke forms and stroke sequence (Giles & Terrell, 1997; Holmes, Malone, & Redenbach, 2008). The study of Yu, Gong, Qiu, & Zhou (2011) presented the participants with the correct stroke sequence, 2-stroke reversal or 3-stroke reversal during fMRI scan. The activation in the premotor-parietal network under the presence of correct stroke sequences indicated general sequential skill was involved in Chinese stroke perception (Yu et al., 2011). Siok and Fletcher (2001) also revealed the significant predicting power of visual sequential memory in Grade 1 Chinese character reading, suggesting the vital role of visual sequential memory in Chinese word learning.

Visual spatial memory

The orthography of Chinese is created by various spatial arrangements of strokes and stroke forms. Several studies have demonstrated the importance of visual spatial memory in Chinese character processing and recognition (Hoosain, 1991; Mcbride-Chang et al., 2005; Tan et al., 2001; Tavassoli, 2002). Mcbride-Chang et al. (2005) has shown a strong association between visual-spatial relations and Chinese character recognition in Hong Kong and China kindergarteners after statistically controlling for age. Meanwhile, when compared the visual spatial memory between Chinese-English bilinguals and native English monolinguals, it is discovered that Chinese-English bilinguals had a significantly better visual spatial memory than native English, indicating the logographic Chinese script facilitates spatial memory (Tavassoli, 2002).

Common stroke errors and the developmental patterns of handwriting

Children's handwriting errors are viewed as a window to see children's orthographic knowledge development and the strategy shift (Shen & Bear, 2000). Different studies have adopted different classification systems in categorizing handwriting errors. In the study of Shen and Bear (2000), the spelling errors of 3000 primary school children in China were analyzed and categorized based on the three linguistic principles of Chinese characters, including phonologically based errors, orthographic errors and semantic errors. The results revealed the predomination of phonologically based error across Grades 1–6. However, phonologically based error had a significant negative linear association with grades while orthographic and semantic error categories showed the opposite direction of association with grades (Shen & Bear, 2000). The findings suggested an increasing complexity in Mainland children's orthographic knowledge. As the grade levels increased, children used fewer phonological strategies in remembering a character but paying more attention to the graphemic and semantic components of the character (Shen & Bear, 2000).

Tong, McBride-Chang, Shu, and Wong (2009) and Yeung et al. (2013) replicated Shen and Bear's (2000) research by conducting a longitudinal study on the spelling errors on primary school children in Hong Kong. Unlike the predomination of phonologically based errors found in mainland China children, orthographic errors and semantic errors were predominated in the studies of Tong et al. (2009) and Yeung et al. (2013) respectively. The different error patterns between children from China and Hong Kong could be attributed to the different learning methods of Chinese. Unlike children in mainland China who adopt a pinyin system in learning Chinese, children in Hong Kong use a whole-word approach (Yeung et al., 2011). The lack of any phonetic system in assisting the learning process in Hong Kong may lead to the different pattern of spelling errors made by Hong Kong and mainland China primary school children.

Besides classifying children's spelling errors into phonologically based errors, orthographic errors and semantic errors categories, Law et al. (1998) and Tse, Thanapalan, and Chan (2014) have looked into the orthographic error category. Law et al. (1998) grouped Grade 1 children's spelling errors into stroke production errors, stroke sequence errors and wrong decomposition of characters into components. Stroke production error is the inability to recognize and produce different stroke forms which includes stroke reversal errors, concatenation of separate strokes and broken strokes. Stroke sequence error focuses on the stroke sequence rules and to see whether children comply with the rules. The wrong decomposition of characters is about the illogical breakdown of a compound character into different stroke forms. Results postulated that stroke sequence error was the most prevalent type of error, especially found within individual components of the characters (Law et al., 1998; Tse et al., 2014). Meanwhile, children, especially for those who had poor legibility, tended to write strokes that form less-intact character configuration (Tse et al., 2014). For instance, they may produce strokes that scatter beyond the writing grid or with disproportional size etc. This showed a correlation with poor visuospatial working memory and executive function (Chiappe, Hascher, & Siegel, 2000; Reiter, Tucha, & Lange, 2005; Rosenblum, Aloni, & Josman, 2010). Children may have difficulties in visualizing and retaining the visuospatial information of strokes that hindered the execution of hand movements in writing Chinese characters (Tse et al., 2014).

Lam et al. (2011) have analyzed orthographic errors from a different perspective. Instead of focusing on children's spelling errors, stroke errors from copying task was examined in Grades 2–6 typical children and children with dyslexia. Errors were classified into seven groups including missing stroke errors, additional stroke errors, mirrored stroke errors, inverted stroke errors, broken stroke errors, concatenated stroke errors and crossing stroke errors (Lam et al., 2011). Results revealed that dyslexic children had significantly greater numbers of total stroke errors, missing stroke errors and concatenated stroke errors when compared with typical children of the same age (Lam et al., 2011). However, as grade levels increased, the total number of stroke errors decreased in both groups of children (Lam et al., 2011). The higher writing accuracy in upper-grade children may be due to the better developed fine motor skills and visual perceptual skills (Lam et al., 2011). Therefore, upper-grade students can avoid writing errors such as missing or additional strokes and they can have a better spatial arrangement of each character and the radicals.

Important predictors of Chinese word spelling

Research has shown that morphological awareness, rapid naming and stroke knowledge are important in predicting children's Chinese spelling abilities (Ho, Chan, Tsang, & Lee, 2002; Lo et al., 2016; Tong et al., 2009; Yeung et al., 2011).

Morphological awareness

Homophone sensitivity is one of the major aspects of morphological awareness in Chinese (Liu & McBride-Chang, 2010). With the presence of a large number of homophones in Chinese, phonological information alone is not reliable enough to set characters apart. So, knowing that morphemes with the same pronunciation may have distinct meanings is important. Studies have found that morphological awareness helps distinguish homophones based on their meanings and context. This skill was found to be a significant predictor in Chinese spelling abilities (Lo et al., 2016; Tong et al., 2009; Yeung et al., 2011).

Rapid naming

Studies have shown a close connection between rapid naming tasks and Chinese spelling abilities in children (Lo et al., 2016; Yeung et al., 2011, 2013). Rapid naming involves the association between phonological and orthographical abilities which sheds light on mental orthographic representation (**Stainthorp, Powell, & Stuart, 2013; Yeung et al., 2011). Meanwhile, Chinese dictation involves the transition from phonological inputs to orthographical inputs. Since both tasks require name retrieval from memory and automatic extraction of orthographic information, it helps explain why rapid naming is a cognitive predictor of Chinese spelling (Ho et al., 2002; Yeung et al., 2013).

Stroke knowledge

Mastering correct stroke forms and stroke sequences may facilitate Chinese spelling. Lo et al. (2016) have shown its significant contribution to Chinese word spelling in Hong Kong Grades 1 and 2. This may be due to the fact that Grade 1 students need to be familiar with the basic stroke forms and stroke sequences when they learn to write and spell Chinese characters. This remains crucial in the following year. Lam and McBride-Chang (2018) have further found that stroke order was a unique correlate in Chinese word spelling performance in Hong Kong K3 (the third level of kindergarten) children, after statistically controlling for age, IQ and vocabulary knowledge. Nevertheless, the unique contribution of stroke order has vanished when other cognitive skills were included such as morphological awareness, phonological awareness and semantic radical awareness (Lam & McBride-Chang, 2018).

Present study

A growing amount of recent research has focused on handwriting skills and children's spelling abilities. For instance, Lam and McBride-Chang (2018) and Wang, McBride-Chang, & Chan (2014) have used a copying task to measure kindergarteners' handwriting abilities and related them to Chinese reading and writing abilities. Tse, Siu, & Li-Tsang (2018) has scored the Chinese visual-orthographic copying task based on four features chosen from Tseng Handwriting Problem Checklist (Tseng, 1993), including following a square configuration, number of strokes, spatial relationship and size and spacing. Nevertheless, limited studies have categorized errors based on children's performance in the copying task and analyze their implicatures accordingly. To address the research gaps aforementioned, the present study had 4 aims. It first aimed to identify the common stroke errors made by Grade 1 and 3 Chinese children. Secondly, it aimed to compare the error patterns between Grade 1 and 3 children to investigate developmental changes across grades. Thirdly, associations between common errors and cognitive skills were examined to identify the cognitive implications of these common errors. Fourthly, factors predicting Chinese spelling ability such as different types of stroke errors and other cognitive-linguistic skills were focused.

Grades 1 and 3 children were chosen as they are undergoing different stages of Chinese spelling and orthographical knowledge development. For Grade 1 children, they are at a beginning stage in which they have acquired structural knowledge and only started to grasp phonetic knowledge (Ho et al., 2003). As Grade 3 children have learnt around 500–600 new character each year since Grade 2, their spelling ability and orthographical knowledge have improved significantly like mastering a fairly complete set of phonetic knowledge (Chung & Leung, 2008; Ho et al., 2003; Yeung et al., 2013). The stroke errors made by Grade 1 and Grade 3 students were collected and analyzed based on the Chinese Character Copying Task. With references of Shen and Bear (2000), Law et al. (1998) and Lam et al. (2011), stroke errors were categorized into six major types: (1) addition or deletion of stroke, (2) broken or concatenated stroke, (3) wrong stroke form, (4) wrong stroke sequence, (5) wrong spatial arrangement and (6) unclassified. Details of the error categories will be provided in the Method section. It is hypothesized that wrong stroke sequence is the most common type of stroke errors among Grade 1 and 3 students due to the ambiguity and difficulty in remembering and applying stroke sequence rules. Developmental changes across Grades 1–3 children would be expected with a decrease of total stroke errors as grade levels increase.

Concerning about the associations between common errors and cognitive skills, it is hypothesized that addition or deletion of strokes and wrong character configuration would be related to poor visual-orthographic discrimination skills as measured by Chinese Character Matching. With poorer visual-orthographic discrimination skills, children may overlook some visual details of the characters. Meanwhile, wrong stroke sequence and spatial arrangement would suggest poor visual sequential and spatial memory.

It is further hypothesized that morphological awareness, rapid naming and total number of correct stroke sequence would predict children's Chinese spelling ability.

Methods

Participants

A total of 43 Chinese first-grade and third-grade students (21 first-graders with 1.1:1 male to female ratio and 22 third-graders with 1.2:1 male to female ratio) participated in the present study. They came from the same Chinese primary school in Hong Kong. Based on parental reports, all participants were from Cantonese-speaking homes with no learning difficulties. The non-verbal IQ levels of the participants fell between 78 and 120 (mean IQ = 101.86, *SD* = 11.23 for Grade 1 students and mean IQ = 97.91, *SD* = 8.19 for Grade 3 students). One participant had an IQ of 78. Since students studying in mainstreamed school were the focus of the present study, she was retained in the sample. The mean ages of Grade 1 students were 6 years 9 months (age range 72–96 months, *SD* = 7.12) and 8 years 9 months for Grade 3 students (age range 98–120 months, *SD* = 6.32).

Measures

General reasoning ability

Raven's Standard Progressive Matrices was used to assess children's non-verbal matrix reasoning (Raven, 1958). It consists of five sets with 12 items each. The short form (the first three sets) and the full scale was administered to Grade 1 and 3 children respectively. In each item, a target visual matrix was shown with a missing piece. Participants were required to choose the best representation of the missing piece from six to eight alternatives shown the target. Scoring procedures were based on the local norm of Hong Kong children established by the Education Department of the Hong Kong Government in 1986.

Chinese word spelling

Similar to the studies of Lo et al. (2016) and Yeung et al. (2011), a dictation task was adopted to measure the Chinese word spelling abilities of Grade 1 and Grade 3 children. The task was made up of 16 two-character Chinese words. They based on the common vocabularies found in primary school Chinese textbooks《學好中國語文》and《新語文》in the research of Lam (2016). The difficulty ranges from Grade 1 to Grade 3 levels. The experimenter read aloud the stimuli words three times: the first time in isolation, then embedded in a sentence and finally repeat the words in isolation again. One mark was given to each correct Chinese character that made up to 32 marks in total.

Visual-orthographic ability

Visual-orthographic ability was tested by Chinese Character Matching, modeled after the Chinese Character Matching test from The Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students Second Edition (Ho et al., 2007). It contains 18 items requiring children to find a Chinese character identical to the target character (shown on the left) among the six choices (shown on the right). Only one of them is correct and each of the remaining five choices contain one of the errors below: addition/deletion of stroke, broken/concatenated stroke, wrong spatial arrangement, wrong stroke form or other types of error including mirror or wrong word. The score was calculated based on the number of correct answers. This enables us to test children's visual-orthographical discrimination ability and sheds light on the common errors made in Chinese character recognition.

Visual sequential-spatial memory

To measure the visual sequential-spatial memory of participants, Corsi Block-Tapping Test was adopted (Corsi, 1972). The test consisted of a board (280 × 230 mm) mounted with nine cubes (30 × 30 × 30 mm) and digits 1–9 were written on one side of the cubes which were visible only by the experimenter. The blocks were displayed in a random manner. The experimenter then tapped the cubes one at a time in a fixed order and the participants were instructed to repeat the exact tapping sequence. Excluding the practice trial, there were 14 items in this test with 7 difficulty levels. After passing one level, one more tap would be added in the following level. The test was terminated when participants failed in both items of the same level or finished all 14 items. One mark was given when participants successfully recalled the whole sequence and the full mark was 14.

Morphological awareness

The Morpheme Identification Task used in Lo et al. (2016) and Yeung et al. (2011), which was modeled after the task of McBride-Chang et al. (2003), was used to assess children's abilities in distinguishing the meanings of Chinese homophones and homographs. The test consists of 15 items. In each item, three two-syllable Chinese vocabularies were orally presented to participants. All the words had an identical pronunciation at the same position but one of homophones or homographs shared a different semantic meaning with the other two. For instance, 學院 (school,/hok6 jyun2/), 醫院 (hospital,/ji1 jyun2/) and 藥丸(pills,/

joek6 jyun2/). The homophones in the first two words have the same meaning of indicating a place but the homophone in the last word means balls or pills. Participants were required to identify the two vocabularies that had the same meaning by circling the number (1, 2, 3) of the associated words based on the presentation order. Printed words were not provided to the participants to minimize the effect of orthographic knowledge on this task. One mark would be given to answer with correct identification of the two words and the full mark was 15.

Rapid naming

A rapid naming task was used to measure participants' rapid automatized naming (Denckla & Rudel, 1976). Five digits including 1, 2, 5, 6 and 8 were printed on a 5×8 matrix on an A4 size paper. Participants were required to name the digits from left to right and top to bottom as fast as possible. They had to name them twice. The errors were marked and the average time would be computed to the nearest 1/100 s.

Stroke knowledge

Chinese Character Copying task was used for analyzing stroke error types and the total number of correct stroke sequences produced by participants. Templates of eight Chinese characters were displayed on the left-hand side and participants were required to copy the templates into the squares on the right with the same word size. There is no time limit for each item. Their copying processes were videotaped for the analysis of the stroke sequences. Unknown characters with higher visual complexity were selected to test the copying skills and the application of stroke sequence rules of the participants. They were adopted from Chinese Lexical Lists for Primary Learning of Key Stage 2 (Grades 4–6) level and List of Written Form of Commonly-used Chinese Characters (Education Bureau, 2007). The copying template covered all the six basic stroke forms and all the six stroke sequence rules of Chinese characters to ensure the occurrence of the potential stroke errors. Details of the error analysis and error types will be provided later. Meanwhile, the scoring system of the total number of correct stroke sequences is adapted from the study of Lam and McBride-Chang (2018) in which one mark was given for each correct stroke sequence. The full mark is 142. Of all 43 children's handwriting samples, 13 of them (30.23%) were coded by two independent coders. Their interrater reliabilities were measured and expressed in Cohen's kappa coefficient. When there was scoring difference, the scoring rubrics would be discussed between the two raters until a consensus was reached.

Procedure

Participants were assessed in classrooms of the primary school. Tasks on general reasoning ability, visual-orthographic discrimination ability, morphological awareness and Chinese word spelling were conducted in a group format. Practice items with detailed instructions and explanations of the answers were provided before the start of each task to allow students to familiarize themselves with the requirements of the corresponding tasks. Students were made sure that all the practice items were answered correctly before moving on to the test's items. Tasks on visual sequential-spatial memory, stroke knowledge and rapid naming were conducted individually. The writing process of the copying task was videotaped to analyze the errors on stroke sequence. All the tests were administered with a random sequence. The duration of the whole testing session lasted for around 120 min. Short breaks were given between the tests. All the tasks were assessed in the middle of the academic year to minimize any disturbance due to the difference in teaching pace.

Error types of Chinese character copying task

Eight types of errors could be identified in the Chinese Character Copying task. The categorization of the errors was based on Tseng Handwriting Problem Checklist (Tseng, 1993), Law et al. (1998), Tse et al. (2014) and Lam et al. (2011). When children committed the same error once or more, only one error was counted whereas zero error indicated the absence of error in a certain category.

Addition/deletion of stroke

The stroke error was classified as addition/deletion of stroke when additional stroke(s) or stroke omission(s) was found in student's answer.

Broken/concatenated stroke

Broken stroke is an error which breaks a basic stroke into smaller segments. An example of the '屮' component found in character '皺' is shown in Fig. 3. On the other hand, concatenated stroke is where separate strokes were wrongly combined to form an illegal basic stroke. The common example is when writing the word '鼎' as shown in Fig. 4.

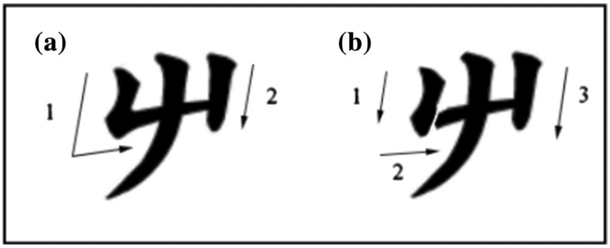


Fig. 3 **a** The correct decomposition and stroke sequence for writing the component '屮' whereas **b** the common broken stroke error committed by students with the first stroke wrongly broken into two strokes

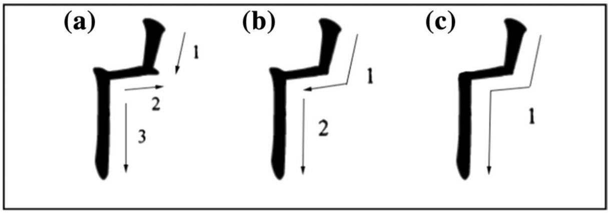


Fig. 4 **a** The correct decomposition and stroke sequence for writing the component '⼚' whereas **b** and **c** the common concatenated stroke errors committed by students with two or three strokes wrongly concatenated into one illegal stroke

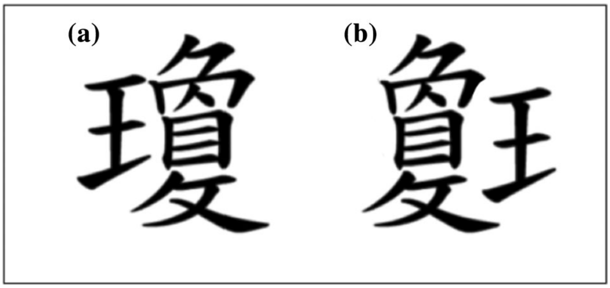


Fig. 5 **a** The correct spatial arrangement of the character '瓊' where the semantic radical '王' is placed on the left-hand side of the whole word; **b** shows the wrong spatial arrangement where the semantic radical is wrongly placed on the right

Wrong stroke sequence

Students' writing sequences were marked based on the stroke sequences found in the Lexical Lists for Primary Schools in Hong Kong which was created by Hong Kong Education Bureau to promote and teach the six stroke sequence rules.

Wrong spatial arrangement

This is the error where the character component was misplaced. For example, as indicated in Fig. 5, the radical of the word '王' should be placed on the left-hand side of the character but the student wrongly wrote place it on the right-hand side. One score was given to one error on wrong spatial arrangement.

Wrong stroke form

This is the error where students wrongly copied the stroke form of the word template so that it became another valid stroke form as shown in Fig. 6.

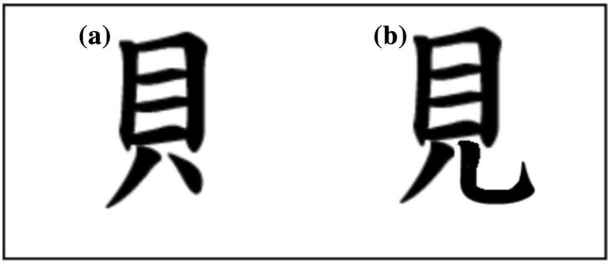


Fig. 6 **a** The correct stroke form of writing the component '貝' whereas **b** one wrong stroke form error by replacing the '丶' (dot) with a '乚'

Poor planning with self-correction

Students might have poor planning when they were writing the character. For example, in writing the word '齊', the component '亠' may not be large enough to cover the components below as shown in Fig. 7. When the student realized the problem and corrected it afterward, it is regarded as this type of error. Though this type of error may be confused with broken stroke error, they are different in nature. Students committed broken stroke error may have wrong concepts of basic stroke or word form which led to such error. However, students having errors on poor planning with self-correction may not have such problems. This type of error emphasized on the lack of or poor planning before writing the character or components.

Poor character configuration

This type of error focuses on the structure and proportion of the character components. For instance, as shown in Fig. 8, the radical of the word '瀟' should be placed on the left-hand side of the whole word but the student wrongly wrote it under the component '艹'.

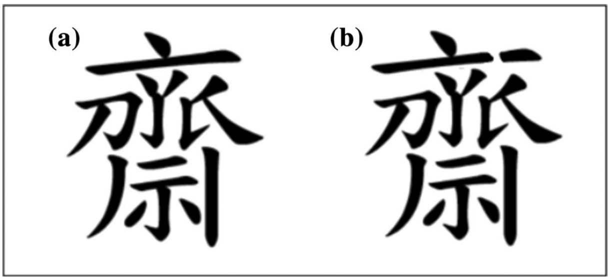


Fig. 7 **a** The correct way in writing the character '齋' whereas **b** the error of poor planning with self-correction as the student may realize the problem after finished writing the character but he/she corrected it by adding a little segment to lengthen the '亠' component

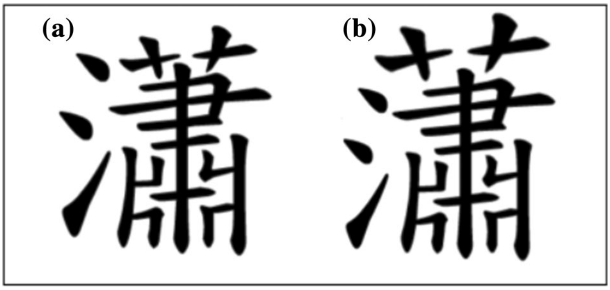


Fig. 8 **a** The correct spatial arrangement of the character '瀟' where the semantic radical is placed on the left-hand side of the whole word; **b** the wrong spatial arrangement where the semantic radical is wrongly placed below the component '艹'

Unclassified

Any other stroke errors which did not belong to the above groups were classified as this type of error. It was dropped in further analysis.

Results

Descriptive analysis

Table 2 shows the mean scores, ranges, standard deviations and reliabilities of all the measures administered in the present study. The reliability coefficients ranged from .61 to .93. The reliability of the rapid naming shown in Table 2 is test–retest reliability. Inter-rater reliability calculated based on the raw score for Chinese Copying Task. The remaining tasks are all internal consistency reliabilities.

Common stroke errors

The percentage of different types of stroke error made by Grades 1 and 3 students are shown in Table 3. Equal weighting of error types was assumed in the analysis. The result of one-way ANOVA revealed that there were statistically significant differences between types of stroke errors ($F(4, 39) = 114.17$, $p < .001$). The result of post hoc test was displayed in Table 4. Among all types of stroke errors, a majority of children have committed wrong stroke sequence with 32%. Its mean error ($M = 6.14$, $SD = 1.08$) was significantly higher than those of the remaining types of stroke error at $p < .001$. It was followed by broken/concatenated stroke and wrong character configuration which accounted for 19% and 18% respectively. The mean error of participants for broken/concatenated stroke ($M = 3.81$, $SD = 1.74$) does not significantly different from that of wrong character configuration ($M = 3.79$, $SD = 1.85$) but was significantly higher than the mean errors of poor planning with self-correction ($M = 2.05$, $SD = 1.69$) and wrong stroke form ($M = 1.44$, $SD = 1.12$)

Table 2 Reliabilities, means, standard deviation and ranges of the measures conducted in the present study (N = 43)

Variables	Reliability coefficient	Range	Mean	SD
Age (total)		72–120	93.42	13.90
Age (Grade 1)		72–96	81.07	7.12
Age (Grade 3)		98–120	105.21	6.32
IQ		78–126	99.84	9.88
Chinese word spelling	.93	7–32	19.51	7.54
Chinese copying task	.90	12–29	20.10	3.94
Added/deleted stroke	.92	0–2	.02	.64
Broken/concatenated stroke	.91	1–7	.05	1.74
Wrong stroke sequence	.85	4–8	.16	1.08
Wrong spatial arrangement	.89	0–2	.02	.70
Wrong stroke form	.80	0–3	.02	1.12
Poor planning with self-corr.	.81	0–6	.05	1.69
Wrong character configuration	.81	0–7	.14	1.85
Unclassified	.90	0–4	.02	1.41
Total correct stroke sequence	.78	88–126	111.49	9.49
Rapid naming	.85	9.77–46.43	23.64	8.68
Morphological awareness	.64	4–22	9.93	3.28
Visual-orthographic discrimination ability	.78	1–18	9.91	4.21
Visual sequential and spatial memory	.61	2–9	5.91	1.80

Cronbach's alpha coefficients were computed for Chinese word spelling, Chinese copying task, morphological awareness, visual-orthographic discrimination ability and visual sequential and spatial memory. Pearson's r coefficient was computed for rapid naming. Kappa's coefficient was computed for Chinese Copying Task

Table 3 Distribution of different types of stroke error

Error type	Average percentage across participants
Wrong stroke sequence	32
Broken/concatenated stroke	19
Wrong character configuration	18
Poor-planning with self-correction	10
Unclassified	10
Wrong stroke form	7
Wrong spatial arrangement	2
Addition/deletion of stroke	2

at $p < .001$. Poor planning with self-correction contributed to 10% to the total stroke error whereas wrong stroke form accounted for 7%. However, the mean error of participants for poor planning with self-correction does not significantly different from that of wrong stroke form. Since floor effect was observed in wrong spatial

Table 4 Bonferroni comparisons of the average error of different types of stroke error

(I) Type of error	(J) Type of error	Mean difference (I–J)	SE
Wrong stroke sequence	Broken/concatenated stroke	2.33***	.31
	Wrong character configuration	2.35***	.29
	Poor-planning with self-correction	4.09***	.31
	Wrong stroke form	4.67***	.24
Broken/concatenated stroke	Wrong character configuration	.02	.37
	Poor-planning with self-correction	1.77***	.36
	Wrong stroke form	2.37***	.24
Wrong character configuration	Poor-planning with self-correction	1.74***	.42
	Wrong stroke form	2.35***	.31
Poor-planning with Self-correction	Wrong stroke form	.61	.33

***$p < .001$

arrangement and addition/deletion of stroke which each only accounted for 2%, they were dropped for further analysis.

Three examples were mentioned in Tables 5, 6 and 7 to illustrate the top three most common stroke errors and their major mistakes. 27.4% of students committed wrong stroke sequence error within the character ‘龜’, followed by 21.7% and 15.8% of children in characters ‘瀟’ and ‘攀’ respectively. It is found that children violated different stroke sequential rules in different characters. For instance, in the character ‘龜’, most of them violated the rule of writing from the left to the right ‘先左後右’ by writing the component ‘⺕’ before ‘彐’. Meanwhile, 23.2% of students wrongly broke or concatenated the stroke in writing the ‘⻳’ component of the character ‘龜’ and the ‘丬’ component of the character ‘鼎’, followed by 21.5% in ‘齋’. As for wrong character configuration error, 24.0% of children committed it in the character ‘瀟’ and their major difficulty lies on the component ‘肅’ while 14.5% and 13.5% of children had this type of error in characters ‘贏’ and ‘鼎’.

Grade difference in error patterns

Independent-samples t-tests were conducted to compare the scores between Grade 1 and Grade 3 students on total error and different types of stroke error, including addition/deletion of stroke, broken/concatenated stroke, wrong stroke sequence, wrong spatial arrangement, wrong stroke form, poor planning with self-correction and wrong character configuration. The results are shown in Table 8. Overall speaking, there was no significant difference between Grade 1 and Grade 3 students on the scores of total stroke error and most of the different types of stroke error. Significant results were found in the stroke errors of wrong stroke sequence and wrong character configuration. Grade 1 students made significantly more errors of wrong stroke sequence ($M = 6.48$, $SD = .93$) when compared with Grade 3 students ($M = 5.82$, $SD = 1.14$); $t(41) = 2.07$, $p < .05$. Grade 1 students also committed significantly more

Table 5 The top three characters with the highest percentage of stroke sequence error and the major mistakes

Character	Stroke error—wrong stroke sequence	
	% of frequency	Major mistake
龜	27.4	Violate the rule of writing from the left to the right (先左後右) By writing the component '' before ''
瀟	21.7	Violate the rule of horizontal strokes should be written before vertical one (先橫後豎) 
攀	15.8	Violate the rule of writing the middle component before the parts on either side (先中間後兩邊) 

Table 6 The top three characters with the highest percentage of broken/concatenated stroke error and the major mistakes

Character	Stroke error—broken/concatenated stroke	
	% of frequency	Major mistake
龜	23.2	
鼎	23.2	
齋	21.5	

Table 7 The top three characters with the highest percentage of character configuration error and the major mistakes

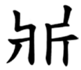
Character	Stroke error—wrong character configuration	
	% of frequency	Major Mistake
瀟	24.0	
贏	14.5	
鼎	13.5	

Table 8 Independent *t* test results comparing the scores between Grade 1 and Grade 3 on different types of stroke error and total error

	Grade		*t*	*df*
	Grade 1	Grade 3		
Added/deleted stroke	0.19	0.45	− 1.36	41
Broken/concatenated stroke	3.62	4.00	− 0.72	41
Wrong stroke sequence	6.48	5.82	2.07*	41
Wrong spatial arrangement	0.52	0.41	.53	41
Wrong stroke form	1.14	1.73	− 1.75	41
Poor planning with self-corr.	1.76	2.32	− 1.08	41
Wrong character configuration	4.57	3.04	2.95**	41
Total error	20.52	19.36	0.96	41

*$p < .05$; **$p < .01$; ***$p < .001$

errors of wrong character configuration ($M = 4.57$, $SD = 1.60$) when compared with Grade 3 students ($M = 3.05$, $SD = 1.79$); $t(41) = 2.95$, $p < .01$.

Correlation

To examine the implications of the common errors, correlations were conducted. Correlations among age, IQ, grade, word spelling, different types of stroke errors, total stroke errors, total correct stroke sequences, rapid naming, morphological awareness, visual-orthographic discrimination ability and visual sequential and spatial memory are shown in Table 9. Unlike the hypothesis, most stroke errors neither correlated with visual-orthographic discrimination ability nor visual sequential and spatial memory. However, wrong stroke sequence error was found to be negatively correlated with visual-orthographic discrimination ability, $r = -.38$, $p < .05$ and visual sequential and spatial memory, $r = -.34$, $p < .05$. Furthermore, wrong character configuration error also had a moderate negative correlation with visual-orthographic discrimination ability, $r = -.51$, $p < .01$ and a negative correlation with visual sequential and spatial memory, $r = -.34$, $p < .05$.

Multiple regression

Hierarchical multiple regression analyses were conducted with Chinese word spelling of Grades 1 and 3 as the dependent variable and the results are shown in Tables 10 and 11. Age and IQ were entered in Step 1 as statistical controls. Since consistent past research indicated the contributions of rapid naming, morphological awareness and orthographic ability to Chinese word spelling, it was expected that similar results would be obtained. Hence, they were entered in Step 2. To address the main research aim of how different types of stroke errors predict Chinese word spelling, wrong character configuration was entered in Step 3 as shown in Table 10 in search of its unique contribution to Chinese spelling ability. Correct stroke sequence was entered in Step 3 as shown in Table 11 for the same rationale. After controlling for other variables, character configuration error had a unique contribution to Grades 1 and 3 students' Chinese word spelling abilities was identified, $F(6, 36) = 22.78$, $p < .001$ with the unique contribution of 6.40%. Morphological awareness, rapid naming and visual-orthographic ability uniquely contributed to 9.00%. Meanwhile, stroke sequence had shown no significant unique contribution to children's Chinese word spelling abilities after controlling age and IQ in Step 1 and entering rapid naming, morphological awareness and orthographic ability in Step 2.

Discussion

Common stroke errors

Wrong stroke sequence

Among all eight categories of errors, wrong stroke sequence was the most common stroke error made by Grades 1 and 3 students, followed by broken or concatenated stroke and wrong character configuration. The results echoed with the findings of Law et al. (1998) and Tse et al. (2014) suggesting that wrong stroke sequence is the most common type of error.

Chinese characters are composed of strokes packed into a square with no clear initial position, unlike English (Chen, 1992; Chen et al., 1993; Tan et al., 1996).

Table 9 Correlations among age, IQ, grade, word spelling, different types of stroke errors, total stroke errors, total correct stroke sequence, rapid naming, morphological awareness, visual-orthographic discrimination ability and visual sequential and spatial memory

	Age	IQ	Grade	WS	A/D	B/C	WSS	WSA	WSF	PP	WCC	TE	CSS	RAN	MA	VDA	VSSM
Age																	
IQ	−.27																
Grade	.88***	−.15															
WS	.78***	−.07	.84***														
A/D	.12	−.26	.21	.10													
B/C	−.03	.22	.11	−.01	−.03												
WSS	−.27	−.16	−.31*	−.39*	−.10	.00											
WSA	−.09	.33*	−.08	−.06	−.29	−.05	−.06										
WSF	.08	−.08	.26	.11	.09	.45**	−.05	.01									
PP	.30	.07	.17	.18	.10	.03	−.02	.00	−.12								
WCC	−.50**	−.17	−.42**	−.64***	.10	.07	.22	.06	.15	−.22							
TE	−.22	−.04	−.15	−.43**	.16	.50**	.29	.16	.49**	.25	.65***						
CSS	.22	−.06	.14	.34*	.02	−.67***	−.48***	.10	−.29	−.03	−.40**	−.61***					
RAN	−.62***	.11	−.73***	−.65***	−.29	.00	.32*	.06	−.27	−.24	.21	.01	−.15				
MA	.67***	−.09	.68***	.69***	.16	−.07	−.31*	−.11	−.00	.26	−.44**	−.30*	.26	−.41**			
VDA	.55***	.01	.46**	.55***	−.23	−.20	−.38*	.07	−.04	.20	−.51**	−.46**	.42**	−.33*	.43**		
VSSM	.05	.25	.11	.18	−.18	−.04	−.34*	.15	−.10	.22	−.34*	−.27	.37*	−.06	.30	.51**	

WS word spelling, *A/D* addition/deletion of stroke, *B/C* broken/concatenated stroke, *WSS* wrong stroke sequence, *WSA* wrong spatial arrangement, *WSF* wrong stroke form, *PP* poor planning with self-correction, *WCC* wrong character configuration, *TE* total error, *CSS* total correct stroke sequence, *RAN* rapid naming, *MA* morphological awareness, *VDA* visual-orthographic discrimination ability, *VSSM* visual sequential and spatial memory

*$p < .05$; **$p < .01$; ***$p < .001$

Table 10 Hierarchical multiple regression equations predicting Chinese word spelling from cognitive-linguistic skills measures after controlling age, IQ and visual-orthographic discrimination ability

Final step predictor	Word spelling				
	B	*SE*	*β*	R^2	R^2 change
Step 1					
Age	.13	.08	.24	.64	.64***
IQ	.00	.06	.00		
Step 2					
Visual-orthographic discrimination ability	.09	.17	.05		
Rapid naming	−.27	.09	−.32**	.73	.09*
Morphological awareness	.52	.24	.23*		
Step 3					
Wrong character configuration	−1.35	.41	−.33**	.79	.06**

*$p<.05$; **$p<.01$; ***$p<.001$

Table 11 Hierarchical multiple regression equations predicting chinese word spelling from cognitive-linguistic skills measures after controlling age, IQ and visual-orthographic discrimination ability

Final step predictor	Word spelling				
	B	*SE*	*β*	R^2	R^2 change
Step 1					
Age	.23	.08	.42**	.64	.64***
IQ	.07	.06	.10		
Step 2					
Visual-orthographic discrimination ability	.16	.20	.09	.73	.09*
Rapid Naming	−.22	.10	−.25*		
Morphological awareness	.56	.27	.25*		
Step 3					
Correct stroke sequence	.90	.08	.11	.74	.01

*$p<.05$; **$p<.01$; ***$p<.001$

Children need to use the component decomposition skills taught at schools to process compound characters so as to apply the stroke sequence rules in writing Chinese characters (Siok & Feldman, 1996; Zhu & Taft, 1994). The present results supported Law et al. (1998). When children write unfamiliar characters with unfamiliar components, they have more difficulties in arranging the components within characters in correct sequence as well as writing correct stroke sequences within the components.

In *wrong sequencing of components within characters,* the three characters with the highest percentage of wrong stroke sequence error were '龜', '瀟' and '攀'. They were unknown characters to lower-grade students and they carried some unfamiliar components and contained the rule 'write the middle component before writing either side' '先中間後兩邊'. In the character '龜', children often violated the rule of writing from the left to the right ‘先左後右’ by writing the component ‘⺕’ before ‘彐’ as it seems time-saving to write the ‘⺕’ component after writing the vertical line located on the right ‘电’.

*In wrong stroke sequence within a component, the m*ajor difficulty lied on the word ‘瀟’ in which most children made stroke sequence error when writing the component ‘⺻’. Instead of writing all the horizontal lines after writing the vertical one, they wrote the horizontal line at last as shown in Fig. 9. This may suggest that students have difficulties applying some stroke sequence rules to unfamiliar characters, especially the ones containing unfamiliar components.

Although wrong stroke sequence was found to be the most common stroke error committed by Grades 1 and 3 students, the insignificant result of the multiple regression showed that it may not be highly related to children's Chinese spelling abilities. This may due to the overall undistorted mental representation of the characters. Chinese characters are more often to be mentally represented in terms of radicals or components instead of smaller units such as strokes (Ding, Peng, & Taft, 2004). Therefore, the wrong stroke sequence may have no or little impact on the mental representation of the characters and hence may not have a significant association with their spelling abilities. Nevertheless, it was found to correlate with visual cognitive skills, particularly visual-orthographic discrimination skills and visual sequential and spatial memory, which will be further elaborated in later section.

Broken or concatenated stroke

Broken or concatenated stroke was also one of the common stroke errors made by children. Similar to the findings of Law et al. (1998), this kind of error, especially broken strokes, existed mainly in less familiar characters. Law et al. (1998) further pointed out the even if children could distinguish and write a particular composite stroke correctly in a familiar character, they still failed to transfer and apply the knowledge to a less familiar word. This helps explain the high frequency of broken strokes existed in characters ‘龜’ and ‘鼎’ which contain uncommon components or stroke forms of ‘电’ and ‘卜’ respectively.

As mentioned in Law et al. (1998), the occurrence rate for concatenated stroke error was especially high for ‘maze’ structure as reflected in the character ‘鼎’ which requires children to break and concatenate strokes in a correct way as shown in Fig. 10. It may imply that teachers need to pay attention to characters having a ‘maze-like’ component

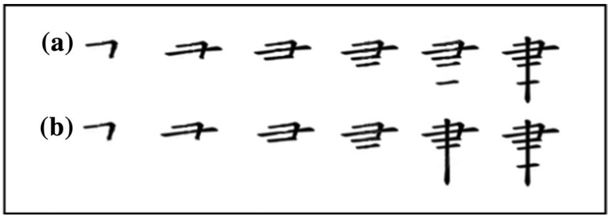


Fig. 9 **a** The correct stroke sequence of writing the component ‘⺻’ following the rule ‘先横後豎’; **b** the common wrong stroke sequence of writing component ‘⺻’ with the rule ‘先横後豎’ violated

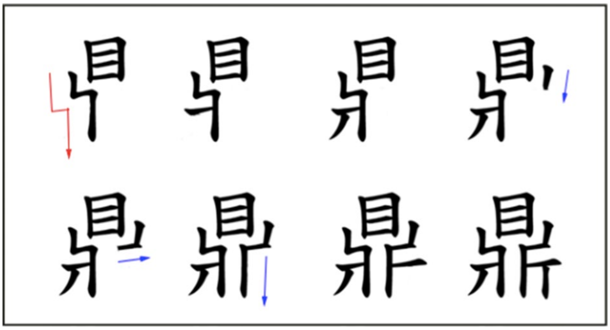


Fig. 10 It shows part of the correct stroke sequence of the character '鼎' with the red arrow indicates the concatenated stroke whereas the blue arrows indicate the broken strokes

by teaching children explicitly the correct ways to decompose and write it. This can ensure children write the components or characters in a correct and consistent way to reduce memory load (Law et al., 1998; Meulenbroek & Hylkema, 1989; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989).

Wrong character configuration

Another common type of stroke error is wrong character configuration. Written Chinese emphasizes a lot on the accuracy in spatial relationships between radicals and a character while this is also a challenge to all school-aged children (Ho, Chan, Lee, Tsang, & Luan, 2004; Tse et al., 2014). The present results supported the findings of Tseng and Hsueh (1997) and Tse et al. (2014) in which character configuration error was prevalent among children, especially those with poor legibility.

Among the three characters with the highest percentage of wrong character configuration ('瀟', '鼎' and '贏'), children show difficulties in allocating proportional spacing between components in all three characters. They often allot too much space within the components '肅', '爿片' and '月貝凡' as shown as Fig. 11. Moreover, disproportionate size among components of a character can also be observed in '月貝凡' of the character '贏' reflected in Fig. 12. These errors related to character configuration is found to be associated with children's Chinese spelling abilities and it will be further discussed later. Since all these characters have relatively complicated and ambiguous structure, it requires more time and experience for children to master the appropriate space allocated between radicals and the proportional sizes of components. This can explain the significant difference found between Grades 1 and 3 students which will be discussed in detail in the following section.

Fig. 11 In **a**, **b** and **c**, the figure on the left shows the proportional spacing between components in characters ‘瀟’, ‘鼎’ and ‘贏’ while the figure on the right shows the disproportional spacing between components

Fig. 12 It shows the disproportionate size among components of the character ‘贏’, one of the common character configuration errors of the component ‘月貝凡’ among children

Developmental changes

Mastery of basic stroke patterns and character structures during the preschool period

Floor effect was found in addition or deletion of stroke and wrong spatial arrangement as each of them merely accounted for 2% in total stroke errors. It shared similarity with the results of Shen and Bear (2000) in which addition or deletion error accounted for .58% and 1.72% in Grades 1 and 3 respectively whereas wrong spatial arrangement accounted for .15% and 1.03% in Grades 1 and 3 total errors. Grades 1 and 3 rarely make addition or deletion of stroke and spatial arrangement errors, especially in Chinese Character Copying Task. Therefore, it is suspected that they have mastered basic stroke patterns and character structures in which visual shape discrimination skill facilitates the identification and differentiation of stroke patterns and real non-lexical radicals. This helps minimize these two kinds of error (Laszlo & Bairstow, 1984; Tong & McBride-Chang, 2010).

Gaining competence on stroke sequence rules and correct character configuration from Grade 1 to Grade 3

The results of independent *t* test revealed that Grade 3 students committed significantly fewer errors on wrong stroke sequence and wrong character configuration than Grade 1 students. This suggests an improvement phase can be found between Grades 1 and 3 in mastering stroke sequence rules and character configuration skills. In fact, writing Chinese characters with the correct stroke sequence and character configuration requires time and writing experience to brush up. As grade level increases, there is an increasing demand of academic written work which contains more stroke patterns and with higher complexity (Ho et al., 2003; Lam et al., 2011). Since stroke sequence rules can sometimes be contradicting and ambiguous, knowing more Chinese characters with different complexity allows children to see the patterns of the writing sequences of strokes. This can facilitate their application of the rules. Meanwhile, more complex stroke patterns or characters do not only provide children with more opportunities to train up their writing skills, but they also involve more orthographic knowledge including radical information knowledge and positional knowledge etc. It allows upper-grade students to understand the rationales or rules to write characters with correct character configuration and this helps reduce the number of character configuration errors.

Developing skills on the full mastery of stroke forms in Grade 3

Based on the results of independent t-tests, no significant differences could be spotted between Grades 1 and 3 students for broken or concatenated strokes. However, the distribution of stroke errors reveals that it was one of the common error types for both grades. The results may infer that Grade 3 students still cannot fully master all the stroke forms so they are under ongoing development. Law et al. (1998) also reported that transferring the knowledge of broken or concatenated strokes to less familiar characters was one of the difficulties for children. Hence, it is suspected that children may take the whole period of primary education to fully master all 21–41 stroke forms and to correctly transfer the knowledge to unfamiliar characters which require time and accumulated writing experience.

Although Grade 3 students were expected to make significantly fewer total stroke errors than Grade 1 students, just like the pattern shown in Lam et al. (2011), no significant difference could be found between the two grades. The difference may due to the comparison between different grades. In Lam et al. (2011), students from Grades 2–6 were recruited so a sharp comparison could be made between lower- and upper-grade students. Nevertheless, the present study only compared the total stroke errors between Grades 1 and 3. Since all of them belong to lower elementary level, the difference may not be as obvious as in Lam et al. (2011). Although the current study showed that Grades 1 and 3 students share a similar total number of stroke errors, they have completely different sets of error patterns. Grades 1 and 3 students are undergoing different stages of orthographic development as mentioned above.

Implications of errors for learning

In line with the hypothesis, stroke sequence error showed a negative correlation with visual sequential and spatial memory. The more the stroke sequence errors make, the poorer the visual sequential and spatial memory the children have. As Yu et al. (2011) reported, perceiving Chinese characters involves general sequential skill as stroke sequence rules play an important role in processing logographic characters. The current study reveals that not only stroke perception is associated with general sequential memory, stroke production also correlates with visual sequential memory. However, acquainting with the stroke sequence rules alone is not sufficient enough to form a valid component or character, the strokes need to be arranged into an appropriate position and this skill relies on visual spatial memory (Tavassoli, 2002).

Apart from the correlation found between visual sequential and spatial memory, wrong stroke sequence also had a negative correlation with visual-orthographic discrimination skills. This can be explained by the mental process involved in writing strokes. Since writing stroke in a specific sequence requires children to focus more on individual strokes and their writing sequences, visual-orthographic discrimination skill can facilitate the differentiation of strokes. It shows some similarity with the idea of the pre-alphabetic phase of learning proposed by Ehri's (2005). Children need to make use of their two-dimensional visual-orthographic discrimination skill to recognize isolated strokes and pick up some orthographic features before applying the stroke sequence rules in writing the characters.

In addition, wrong character configuration was negatively correlated with visual-orthographic discrimination skill and visual sequential and spatial memory, suggesting the more the errors on character configuration, the poorer the two cognitive skills are. In fact, Chinese characters are composed of a relatively large number of components. This type of error particularly emphasizes on the whole character structure and the proportion of each component. So, it relies a lot on visual-orthographic discrimination skill to notice the space occupied by each component through comparing their handwriting with the character template (Hoosain, 1991; Taylor & Taylor, 1995). Furthermore, non-linear spatial representation is also one of the features of Chinese characters (Hoosain, 1991; Taylor & Taylor, 1995). Therefore, the abilities to perceive, remember and put different components in order and in a specific two dimensional spatial design are crucial to minimizing character configuration errors (Chiappe et al., 2000; McBride-Chang, 2016; Rosenblum et al., 2010).

However, unlike the hypothesis proposed, no associations were identified between addition or deletion of stroke and visual-orthographic discrimination skill, suggesting that children who commit this type of error more may not relate to having poorer visual-orthographic discrimination skills. The results did not go along with the findings of Lam et al. (2011) which augured that dyslexic children committed more addition or deletion of strokes due to their poor visual perceptual skills, especially their visual-orthographic discrimination skills. To explain the inconsistency in results between Lam et al. (2011) and the present study, we needed to focus on the participants. Since Lam et al. (2011) emphasized more on the primary children with developmental dyslexia, they may have some cognitive differences or deficits when compared with normal-achieving children with the same age and IQ level (Chan, Ho, Tsang, Lee, & Chung, 2003; Ho et al., 2002). Therefore, the concept of 'committing more added or deleted stroke implied having poor visual-orthographic discrimination skills' may only be applicable in dyslexic children but not in the whole spectrum of the normal population. Children with a normal range of reading and writing abilities may already mentally represent Chinese characters in the forms of stroke patterns since Grade 1. So, they do not heavily rely on their visual-orthographic discrimination skills to look for differences. This may explain the facts that no correlations could be found between added or deleted stroke error and visual-orthographic discrimination skills in ordinary Grades 1 and 3 students.

Apart from that, wrong spatial arrangement showed no correlation with visual sequential and spatial memory which went against the hypothesis. Instead of finding this type of error in Chinese Character Copying Task, it could be observed in Chinese dictation task in which children wrote '目木' as '相'. This type of error was more commonly found in dictation task as it involves more visual memory (Tong et al., 2009; Yeung et al., 2013). Spatial arrangement error was analyzed based on the Chinese Character Copying Task and it does not demand much visual memory. Therefore, the link between spatial arrangement error and visual sequential and spatial memory cannot be clearly identified in the present study.

Associations with Chinese spelling abilities

In accordance with the previous studies (Lo et al., 2016; Tong et al., 2009; Yeung et al., 2011), rapid naming and morphological awareness significantly predicted children's Chinese word spelling abilities. Rapid naming involves the direct association between the visual forms and the corresponding sound and this is also one of the core parts of Chinese dictation. So, it becomes a robust predictor of children's Chinese word spelling abilities (Yeung et al., 2013). However, phonological information alone may be unreliable due to the presence of a large number of homophones in Chinese. As a result, morphological awareness, the ability that helps distinguish homophones based on their meanings and context, also shows strong association with Chinese spelling ability.

Stroke sequence knowledge was found to have a significant unique contribution to the third level of kindergarten and Grade 1 Chinese word spelling in Lam and McBride-Chang (2018) and Lo et al. (2016) respectively. However, in the present study, no significant unique contribution could be found. This could be explained by the complexity of the words chosen for the task. In Lo et al. (2016), to measure children's stroke sequence knowledge, participants were only required to write the next stroke. In Lam and McBride-Chang (2018), though participants needed to copy the whole characters, the characters chosen for the handwriting task only ranged from 2 to 11 strokes. Unlike the studies above, the Chinese copying task adopted in the present study was more challenging. The characters used were more complex with the number of strokes ranging from 13 to 21 and students were required to copy the whole characters. Tseng and Chow (2000) mentioned that stroke order writing is a demanding task for children as it involves various visual processing skills. The present study also found significant correlations between stroke sequence and visual-orthographic discrimination ability and that with visual sequential and spatial memory. The more strokes involve in the character, the more demanding the copy becomes. The stroke copying task conducted by Lam and McBride-Chang (2013) found that children may have no problem in writing simple characters with few strokes like '一' (one), '二' (two) or '三' (three). However, children encountered difficulties in writing complicated chapters with more strokes and more complex character configuration like '爺' (grandfather; 13 strokes) or '變' (change; 23 strokes) (Lam & McBride-Chang, 2013). When the processing of strokes becomes more complicated and the knowledge involved is way beyond their current level, children may overlook the basic units (strokes) in the characters. They tend to focus more on the outcome and the similarity between the template and what they have written. Hence, the characters chosen in the Chinese copying task may not able to accurately measure the stroke sequence knowledge of young children who have not yet mastered writing complicated characters. Therefore, the present study failed to find a significant and unique contribution of stroke sequence knowledge in Chinese spelling ability. Future research should use simple chapters with fewer strokes in Chinese copying task.

The results of multiple regression conveyed character configuration error had a significant and unique contribution to Chinese word spelling in which the more the errors, the poorer the spelling abilities. In fact, according to the Model of Orthographic Knowledge Development in Chinese, character configuration knowledge is the first stage of orthographic knowledge development and it serves as a foundation for later stages of development (Ho et al., 2003). Ho et al. (2003) and Shu and Anderson (1999) further reported that by Grade 1 and 2, children should have a basic understanding on compound character configuration. The knowledge of the detailed structure of the components and subcomponents are acquired gradually over the primary school (Ho et al., 2003; Shu & Anderson, 1999). Nevertheless, character configuration is not as simple as it seems because it involves some advanced orthographic knowledge, especially radical knowledge. Mastering radical knowledge allows children to understand the underlying meaning of the components or radicals so that they can arrange a better character configuration. For instance, the character '瀟' means deep and clear water and it can also be used to describe drizzle in '瀟瀟細雨'. In this character, '氵' should enclose the component '蕭' instead of the radical '艹' enclosed the remaining components as shown in Fig. 8. Acquainting with radical information knowledge enables children to understand that '氵' is the semantic radical which give cues to the meaning of the word and it should enclose the phonetic radical '蕭' which provides cues to the sound of the word. So, the character '瀟' has such a character configuration. Since radical knowledge was found to be a significant predictor of Chinese word spelling and it has a close tie with character configuration, this helps explain the unique contribution of character configuration error to Chinese word spelling abilities in Grades 1 and 3 children.

Educational implications

Though a significant and unique contribution to Chinese word spelling abilities cannot be captured in Grade 1, stroke knowledge, especially stroke sequence, is still a crucial component of Chinese handwriting abilities. It did not only facilitate the formation of a consistent memory and memory retrieval, but also found to correlate with some important visual cognitive skills, namely visual-orthographic discrimination skills and visual sequential and spatial memory (Giovanni, 1994; Shimomura, 1980). Therefore, not overlooking the importance of stroke knowledge, schools should continue to teach stroke sequence rules explicitly.

Meanwhile, character configuration seems to be a simple task which is acquired naturally so schools may not teach children explicitly at an early stage. However, the current findings show its unique and significant contribution to Chinese word spelling ability and its close relationship with structural and radical knowledge. Owing to its importance, schools may need to teach character configuration explicitly since kindergarten so as to foster a better foundation for orthographic development as well as Chinese word spelling abilities.

Limitations

Although the present study has brought about some new insights to this under-researched field, it still had some limitations. Firstly, the sample size is small and they all came from the same primary school. Too few children have participated in the research so it is difficult to obtain potential results. For instance, to examine possible developmental changes between Grade 1 and 3 students, it is better to analyze the data by separating the two grades. Though this has been well-considered, the decrease in statistical power after separation makes it difficult to do so. It is hoped that future research could recruit more Grades 1 and 3 children from different primary schools so as to separate the data for more detailed analysis for developmental changes and to generalize the findings.

Secondly, the current research mainly focused on the relationships between children's visual cognitive skills and their handwriting abilities as reflected by stroke errors, ignoring the factor of motor skill which is also a crucial element in handwriting and Chinese word spelling ability (Berninger, 2004; Tse et al., 2014). Since serious handwriting problems were associated with fine motor deficits skills, it is suspected that poor fine motor skills may also contribute to stroke errors, especially wrong character configuration (Cameron et al., 2012; Smits-Engelsman, Niemeijer, & Van Galen, 2001). Moreover, psycho-motor memory may be related to Chinese stroke sequence as a partial activation like finger tracing can facilitate the recall of words (Hoosain, 1991; Yim-Ng, Rosemary, & Jackie, 2000; Zhang & Simon, 1985). Hence, a wrong coding in psycho-motor memory may lead to stroke sequence errors. Handwriting is a complicated visual-perceptual-motor process which requires the integration and synchronization among different aspects (Tse et al., 2014). So, future research should include motor skills and the interactions between various aspects in analyzing stroke errors and Chinese word spelling abilities.

Conclusion

Despite the fact that numerous research has reported factors affecting children's Chinese reading and spelling abilities, limited studies have examined stroke knowledge and looked into this issue through error analysis. In fact, studying stroke errors can be a window in viewing children's orthographic developmental changes as well as the cognitive difficulties implied. The current findings showed that wrong stroke sequence, broken or concatenated strokes and wrong character configuration were the common stroke errors among Grades 1 and 3 students. Based on the patterns of their stroke errors, it is suggested that they are still undergoing a series of orthographic development to minimize certain types of stroke errors, namely broken or concatenated strokes. Meanwhile, both wrong stroke sequence and wrong character configuration are found to be associated with poor visual-orthographic discrimination skills and visual sequential and spatial memory. Most importantly, stroke errors can be further linked with the general linguistic output in which wrong character configuration was a significant predictor of children's Chinese word spelling abilities. Through adopting error analysis to examine stroke errors and Chinese word spelling ability, it is hoped that future research can continue to explore this under-researched topic to facilitate the understanding of children's learning process in Chinese handwriting.

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