Writing to Dictation and Handwriting Performance among Chinese Children with Dyslexia: Relationships with Orthographic Knowledge and Perceptual-motor Skills

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Abstract

The purpose of this study was to investigate the relationships between writing to dictation, handwriting, orthographic, and perceptual-motor skills among Chinese children with dyslexia. A cross-sectional design was used. A total of 45 third graders with dyslexia were assessed. Results of stepwise multiple regression models showed that Chinese character naming was the only predictor associated with word dictation ($\beta = .32$); handwriting speed was related to deficits in rapid automatic naming ($\beta = -.36$) and saccadic efficiency ($\beta = -.29$), and visual-motor integration predicted both of the number of characters exceeded grid ($\beta = -.41$) and variability of character size ($\beta = -.38$). The findings provided support to a multi-stage working memory model of writing for explaining the possible underlying mechanism of writing to dictation and handwriting difficulties.

Keywords: Dyslexia; Chinese; Dictation; Handwriting; Orthographic; Perceptual-Motor Skills

1. Introduction

Learning to write is a core part of the school curriculum in many Chinese-speaking regions, where children start their practice of writing from preschool years (Cheung & Ng, 2003; Lam, Au, Leung, & Li-Tsang, 2011). Primary school children are regularly assessed with writing-to-dictation tasks to evaluate their weekly learning outcomes (Cheung & Ng, 2003). Many school activities also expect children to develop effective handwriting skills to transcribe printed information on the texts so as to produce written answers on papers (Feder & Majnemer, 2007). In a Chinese school population, children with dyslexia are more commonly observed with persistent difficulties in acquiring basic writing skills than reading skills (Leong, Cheng, & Lam, 2000). This study aimed at identifying the factors that may possibly explain different levels of writing difficulties among Chinese children with dyslexia.

1.1. Nature of writing to dictation and handwriting in Chinese language

Writing to dictation is a multi-stage process that starts from the interpretation of auditory sounds as meaningful words, followed by the retrieval of the orthographic forms from the mental lexicon (Rapp & Caramazza, 1997). Because of the monosyllabic nature of the Chinese language, it requires the writers to distinguish the meanings of different homophone characters in the mental lexicon (Han, Song, & Bi, 2012). In addition, due to the logographic nature of the Chinese scripts, the majority of basic writing units in Chinese are non-semantic and non-pronounceable units that are termed *logo-graphemes* (or components) in Chinese psycholinguistics (Lui, Leung, Law, & Fung, 2010). It means that in writing to dictation, the writers need to recall the exact orthographic forms and positioning of these logo-graphemes. Moreover, in order to produce legible handwriting outputs, the writers need to pay attention to the formation of some 31 major stroke forms and six major stroke sequencing rules (see Law, Ki, Chung, Ko, & Lam, 1998, for illustration), and to write every character within the boundary of a square grid (Lam et al., 2011). This is different from the English writing system that requires writers to produce written words from the fixed set of 26 letters on the horizontal grid lines (Figure 1). Leong et al. (2000) suggested that the complex orthographic rules in Chinese writing system is particularly challenging for Chinese children with dyslexia to acquire the basic writing skills.

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1.2. Prevalence of dyslexia among the Chinese population

An epidemiological study found that about 9.8 to 12.6% of Chinese school children were affected by developmental dyslexia in primary school years (Chan, Ho, Tsang, Lee, & Chung, 2007). Among these children, a preliminary study by Ho and colleagues (Ho, Chan, Leung, Lee, & Tsang, 2005) showed that about 26% of them presented with co-morbid symptoms of attention deficits and hyperactive disorders (ADHD), while 10% of them had developmental coordination disorders (DCD). Despite such high prevalence of co-morbidity, researchers reported that the literacy learning difficulties among Chinese children with dyslexia were specifically related to their difficulties in performing cognitive-linguistic tasks such as rapid automatic naming (RAN), orthographic processing, and morphological processing tasks (Ho, Chan, Lee, Tsang, & Luan, 2004; Ho et al., 2005; McBride-Chang, Chung, & Tong, 2011). More recently, it was found that Chinese children with dyslexia might manifest difficulties in performing copying tasks more often than children with typical development (Lam et al., 2011; McBride-Chang et al., 2011). Lam et al. (2011) suggested that the expression of handwriting difficulties among Chinese children with dyslexia, which include a slow handwriting speed, a great average and variability of character size, and a low accuracy in copying, might underpin an immaturity of perceptual-motor and orthographic skills. Stroke errors such as missing strokes and producing concatenated strokes (i.e., inappropriate linking of two separate strokes into one single stroke) in handwriting were especially common among Chinese children with dyslexia (Lam et al., 2011). Another study reported that the ability to copy unfamiliar scripts could uniquely explain 6% of Chinese word reading and 3% of word dictation performance among children with or without dyslexia in the Chinese school population (McBride-Chang et al., 2011). The researchers suggested that inaccuracy in copying among children with dyslexia could reflect developmental problems in visual-motor integration and paying attention to detailed formation of visual-orthographic stimuli (McBride-Chang et al., 2011).

1.3. Purpose of the study

The main purpose of this study was to investigate the orthographic and perceptual-motor factors which might contribute to different levels of writing difficulties among Chinese children with dyslexia in Hong Kong. The target sample included the heterogeneous subtypes of developmental dyslexia with or without co-morbid conditions in attention deficits or fine motor clumsiness. This was taken in consideration of the growing body of research in support of the importance of investigating the learning-related deficits of developmental disorders as a whole (Nicolson & Fawcett, 2007; 2011). This study sought to identify the possible factors that might explain the individual differences in writing to dictation and handwriting among the heterogeneous subtypes of dyslexia. The conceptual framework was taken with references to the multi-stage working memory models of word writing (Berninger, Raskind, Richards, Abbott, & Stock, 2008; Rapp & Caramazza, 1997). These working memory models commonly suggest that there are multiple stages of cognitive process in word writing. In the pre-lexical stage, the auditory stimuli are recoded into the target words through semantic access. In the post-lexical stage, the graphemes of the target written words are retrieved from the mental lexicon. The retrieved graphemes are then temporarily stored in the *graphemic buffer* (Rapp & Caramazza, 1997) of the working memory system before these graphemes are executed manually in the process of handwriting. On the basis of these models, it was hypothesized that among Chinese children with dyslexia, their degree of difficulties in performing Chinese word dictation would be associated with their deficits in lexical and orthographic knowledge (Ho et al., 2004; 2005), as well as their lower efficiency in mapping the orthographic codes to psycho-motor codes of the Chinese characters (Chan, Ho, Tsang, Lee, & Chung, 2006; Tan, Spinks, Eden, Perfetti, & Siok, 2005). Moreover, as the previous studies consistently reported that the RAN deficit was the predominant deficit in Chinese children with dyslexia (e.g., Ho et al., 2004; 2005), it was expected that this study would produce similar result. We hypothesized that the impact of RAN deficits would go beyond the difficulties in Chinese literacy learning (suggested by Ho et al., 2004) to deficiency in handwriting speed, as both RAN and copying tasks require close maintenance of phonological and/or orthographic information of the target stimuli in the working memory system. Additionally, this study attempted to identify the perceptual-motor variables that might significantly explain the individual differences in handwriting performance among Chinese children with dyslexia. The selected variables included the visual-perceptual skills, fine motor skills, visual-motor integration, and oculomotor control, based on the previous studies that reported significant associations between these various perceptual-motor variables with Chinese handwriting performance among primary school children (Cheung, 2007; Chow, Choy, & Mui, 2003; Li-Tsang et al., 2012; Tseng & Chow, 2000). Results of several review studies have suggested that these variables are important components in supporting the development of handwriting skills in elementary school children across cultures (Bellocchi, Muneaux, Bastien-Toniazzo, & Ducrot, 2013; Feder & Majnemer, 2007; Tseng & Cermak, 1993).

2. Materials and Methods

2.1. Design

A cross-sectional design was used to study the inter-relationships between the multiple variables of interests including Chinese word dictation, handwriting performance, lexical knowledge, orthographic awareness, RAN, and other perceptual-motor skills.

2.2. Settings and participants

2.2.1. Sampling method

The participating children in this study were recruited through cluster sampling of families affiliated to a university research center for families of children with dyslexia in Hong Kong. All participants were students in the third grade who studied in mainstream primary schools. All of them completed a three-year kindergarten program in the local territory. Third graders were chosen because they were regarded as having completed their first stage of learning by the Hong Kong Education Bureau (Curriculum Development Council, Hong Kong, China, 2002). It was believed that the test results in this study could reflect their developmental outcomes at the end of the first stage of learning.

2.2.2. Inclusion and exclusion criteria

All of the recruited children were required to receive a diagnosis of developmental dyslexia by registered psychologists within a two-year period according to the diagnostic criteria in Hong Kong. The criteria required the diagnosis of dyslexia based on two conditions: (a) the child had an average or above average range of intelligence based on the Hong Kong Wechsler Intelligence Scale for Children (HK-WISC; Psychological Corporation, 1981); and (b) the child obtained a standardized score that was equivalent to one *SD* below the means of the school population in both of the literacy test domain (i.e., a composite scaled score of three literacy tests, namely, word reading, word dictation, and one-minute reading) and one or more of the six cognitive test domains (e.g., RAN, orthographic awareness) in the Hong Kong Test-Specific Learning Difficulties in Reading and Writing for Primary School Students–2nd Edition (HKT-P[II]; Ho, Chan, Tsang, Lee, & Cheng, 2007). Children who were new immigrants or had other physical disabilities or sensory impairments were excluded from this study.

2.2.3. Screening

Because all of the information regarding the diagnosed conditions of these children was obtained retrospectively from their diagnostic reports, the authors reviewed the background of all of these children by interviewing their parents and reviewing their academic reports at schools, so as to ascertain their literacy learning difficulties. In addition, two screening tests were administered to these children. All of the included children were required to obtain a standardized score that was equivalent to one *SD* below the mean of the school population in both of the Hong Kong Graded Character Naming Test (HKGCNT; a reading test developed by Leung, Cheng-Lai, & Kwan, 2008) and the word dictation subtest of the Hong Kong Test-Specific Learning Difficulties in Reading and Writing for Primary School Students–2nd Edition (HKT-P[II]; Ho et al., 2007). Those who obtained a score that was equivalent to two *SD*s below the mean of the school population in either one of the two tests were also included.

During the case recruitment period, 64 invitations were sent. After the initial screening, four children were excluded because they had a lower than average range of intelligence according to their diagnostic reports written by psychologists; one child was excluded because he studied in an international school where English was the medium of instruction; another two were excluded because their scores in the two screening tests were close to the average range of normal schoolchildren. Twelve parents of these children refused to participate.

2.2.4. Sample characteristics

The mean age of the remaining 45 children was 9.14 years (*SD* = 0.43; range = 8.58 to 10:41). Thirteen (28.9%) of them were female. Their assessment reports indicated that 22.2% had a higher than average range of intelligence, while 26.7% and 8.9% were reported to have symptoms of attention deficits (11 boys and 1 girl) and fine motor clumsiness (4 boys), respectively. The other demographic characteristics are summarized in Table 1.

-- Please insert Table 1 about here --

2.3. Measures

All children were assessed with eight standardized tests. The primary outcome measures were Chinese word dictation and handwriting performance. The secondary outcome measures included character naming, orthographic awareness, and four measures of perceptual-motor skills (i.e., visual-perception skills, fine-motor skills, visual-motor integration, and oculomotor control).

2.3.1. Writing to dictation

The word dictation subtest of the HKT-P(II), developed by Ho et al. (2007), was used. The test is a writing-to-dictation task of 48 two-character Chinese words arranged in the order of increasing difficulty. During the test, the respondents were required to listen to the words read out by the assessor in Cantonese Chinese and write them down correctly on the answer sheet. The total score of the test ranges from 0 to 96, with one point awarded for each correctly-written character. The Guttman split-half reliability coefficient of this test was above .90 (Ho et al., 2007).

2.3.2. Handwriting performance

The Chinese Handwriting Assessment Tool (CHAT; Lam et al., 2011) was used to assess the handwriting performance of the participating children. It is a computerized system that objectively assesses multiple handwriting-related variables, such as writing time and pressure. The technical details of the software program were reported in a previous study (Lam et al., 2011). During the test, each participant was required to copy a standardized template of 90 characters displayed on the computer screen as quickly and as accurately as possible. All of the selected characters in CHAT are taught in the first grade of primary school, and they cover all the six main basic structures and stroke patterns of Chinese characters (Law et al., 1998). The test-retest reliabilities (measured by intra-class correlation coefficients [ICC]) for all parameters of CHAT were between .88 and .93 (Lam et al., 2011). In the current study, the handwriting speed (measured in no. of characters copied per min), pause time to on-paper time ratio, mean pen pressure and variability (measured in Newton) were used for the analysis of *handwriting process*; the total number of characters exceeded grid, average character size and character size variability were used for the analysis of *handwriting product*.

2.3.3. Character naming

The Hong Kong Graded Character Naming Test for Primary School Children (HKGCNT; Leung et al., 2008) was used to assess children's abilities in reading or recognizing Chinese characters. The HKGCNT is a naming test of 150 characters, covering characters of different frequencies and orthographic structures. The test consists of six different lists of characters, designed specifically for each primary school grade. The characters included in HKGCNT were randomly selected from a representative corpus

(Leung, 2007). The split-half reliability (Spearman-Brown coefficient = .94) and test-retest reliability (Pearson's *r* = .98) of HKGCNT were excellent (Leung et al., 2008). The raw score in HKGCNT was used as the outcome measure in this study.

2.3.4. Orthographic awareness

The orthographic awareness test of HKT-P(II), developed by Ho et al. (2007), was used to assess children's overall orthographic awareness. The test contains three subtests, namely, Left/Right Reversal, Lexical Decision and Radical Position. The 70-item Left/Right Reversal subtest assesses children's ability to identify the correct orientation of orthographic units, such as simple Chinese characters and Arabic numbers. The 60-item Lexical Decision subtest assesses children's ability to recognize the correct orthographic structure of Chinese characters. The Radical Position subtest measures children's knowledge of positional regularity of Chinese radicals in 20 multiple choice items. The composite scaled score of the three subtests was used to indicate their orthographic awareness. The Guttman split-half reliability coefficients of these subtests were above .60 (Ho et al., 2007).

2.3.5. Visual-perceptual skills

The Test of Visual Perceptual Skills–3rd Edition (TVPS-3; Martin, 2006) was used to assess children's development of visual-perceptual skills. The TVPS-3 contains seven subtests that assess different areas of visual perception, including four subtests on basic visual processes, one on visual sequential memory, and two on complex visual processes. Each subtest contains 16 test items. Each test item utilizes black-and-white line drawings for assessing children's ability to identify the correct figure that matches the presented drawing from other visually similar drawings. The internal consistency (Cronbach's α = .96) and the test-retest reliability (ICC = .97) of the combined standardized score were excellent (Martin, 2006).

2.3.6. Fine motor skills

A comprehensive picture of the children's motor development was assessed using the Bruininks-Oseretsky Test of Motor Proficiency–2nd edition (BOT-2; Bruininks & Bruininks, 2005). Four subtests were specifically chosen for use in this study to evaluate children's fine motor development, including two subtests on fine manual control, and two subtests on manual coordination. All of these subtests are task-based measurements of fine motor skill development that are relevant to children's performance in school activities, such as writing and drawing. The two composite scaled scores (i.e., fine manual control and manual coordination) of BOT-2 were used as the outcome measures of this study. The two composite scores were reported to be highly consistent measures of children's fine motor proficiency (Cronbach's α = .85–.86), and the test-retest reliability (measured by Pearson's *r*) ranged from .54 to .70 (Bruininks & Bruininks, 2005).

2.3.7. Visual motor integration

The visual-motor integration (VMI) ability of the participants was evaluated by the

Koppitz Developmental Scoring System for the Bender Gestalt Test–2nd Edition (Reynolds, 2007). During the test, the children were instructed to copy 16 increasingly complex figures (i.e., the Bender designs) derived from the theories of Gestalt psychology. The scoring criteria are mostly related to the ratios, orientation and symmetry of different parts of the figures that are reproduced by children. The accuracy of drawing represents their ability to relate visual stimuli to motor responses. The raw score and standard score was used to indicate the overall performance of these children. The reported internal consistency (measured by Cronbach's α) was .88 and the test-retest reliability (measured by Pearson's *r*) was .82 for children and adolescents aged 8 to 17 (Reynolds, 2007).

2.3.8. Ocular-motor control and RAN

The brief Developmental Eye Movement Test (DEM test; Richman & Garzia, 1987) was used to evaluate the ocular-motor control (or saccadic efficiency) and RAN of the participating children. The Cantonese version of the testing procedure was developed by Pang (2004). The DEM test contains two subtests (i.e., vertical and horizontal subtests). The vertical subtest evaluates children's performance in RAN of digital numbers, displayed vertically on the test plate. The horizontal subtest assesses children's oculomotor control in reading digital numbers that are spaced unevenly and horizontally on the test plate. The participants' performances in these two subtests were measured in time and corrected to the nearest 0.1 sec. The measurement adjusted for the number of addition and omission errors according to the test manual (Richman & Garzia, 1987). The ratio of time taken in the horizontal subtests to that of the vertical subtest was used to indicate the oculomotor control (or saccadic efficiency) of these children. This test is a valid measure frequently used by clinicians to screen ocular motor dysfunction. Its concurrent validity with Visagraph III (i.e., an objective clinical tool for assessing saccadic efficiency; Taylor, 2006) and discriminant validity in identifying Chinese children with specific learning difficulties were established in a previous study (Ng, 2007). A satisfactory range of test-retest reliabilities was reported for the measures taken in the DEM test (Pearson's r = .89, .86, and .57 for the test-retest reliabilities of vertical time, horizontal time, and time ratio, respectively; Garzia, Richman, Nicholson, & Gaines, 1990).

2.4. Data collection and analysis

The authors obtained ethics approval from the Research Ethics Committee of The Hong Kong Polytechnic University to undertake this study. The collected data were numerically coded and analyzed using IBM SPSS version 19.0. All assessment data were collected by a trained research assistant and an occupational therapist in June 2009. The demographic data of the participants were summarized with descriptive statistics. The various outcome measures of the participating children were compared with the available normative data matching the characteristics (e.g., age, gender, or academic grade) of this sample using Z-tests. The analysis also compared the performance between those children with co-morbid developmental disorders (i.e., attention deficits and/or fine-motor clumsiness) and those without such conditions in various measures. The associations between the multiple variables were analyzed with Pearson's product-moment correlation coefficients. The variables that were significantly correlated with the primary outcome measures (i.e., word dictation and handwriting) were entered into the multiple regression models using the stepwise method. The stepwise method selected the most significant variable and removed the least significant one from the list of independent variables in each step. This method was recommended for the exploration of significant predictors in the stepwise multiple regression models (Field, 2009). The analyses adjusted the effects of age, gender, intellectual ability, and presentation of other co-morbid developmental disorders because of their known effects on the relationships between our study variables (Chan, Hung, Liu, & Lee, 2008; Lam et al., 2011; McBride-Chang et al., 2011; Tsai, Meng, Hung, Chen, & Lu, 2011). For all statistical analyses, the level of significance was set at $p < .05$ (two-tailed). The Bonferroni correction was used to counteract the accumulative effects of Type I errors in multiple comparisons.

3. Results

3.1. Overall performance in standardized tests among Chinese children with dyslexia

The children's performances in various standardized tests are summarized in Table 2. By comparing their performance with the available normative data, it was found that the children with dyslexia had significantly lower performance than children with typical development (indicated by means and *SD*s from the data collected in the normative sample) in multiple domains. These included their Chinese word dictation ($p < .001$), handwriting speed ($p < .001$), Chinese character naming ($p < .001$), fine manual control ($p = .001$), fine manual coordination ($p < .001$) and RAN (indicated by vertical time in DEM test; $p < .001$). Their mean writing pressure and its variability were significantly lower than those children with typical development, and they had more characters written exceeded the grid and had a higher variability of character size (*p*s < .001). In rapid saccadic movement (as indicated in the horizontal subtest of the DEM test), more reading errors were found in children with dyslexia than that of the typically developing children ($p < .001$). By using a cutoff of two *SD*s below the population mean as a conventional method to indicate a possibly functional impairment (Indrayan, 2013), it was found that 66.7% of the children had severe difficulties in word dictation (i.e., with less than 30% accuracy in writing familiar Chinese words). In addition, 11.1 and 13.3% of the children had deficits in handwriting speed (i.e., with less than seven characters copied per min) and in writing Chinese characters within the boundary of the square grid (i.e., with more than 40% of copied characters written exceeding the grid), respectively. The other major areas of impairment included character naming and RAN, as observed in 46.7 and 35.6% of the sample, respectively. It was, however, observed that the children with dyslexia had relatively high accuracy (80%) in recognizing high-frequency characters, when compared to other Chinese characters with lower frequency of exposure (with only 27 to 45% accuracy). Additionally, none of these children were found to manifest severe difficulties in performing orthographic awareness, visual-perceptual, fine manual control, or VMI tasks.

3.2. Comparisons between children with or without co-morbid developmental disorders

The children with co-morbid developmental disorders in attention deficits and/or fine motor clumsiness had significantly lower handwriting speed (M = 8.55, SD = 2.70 characters copied per min) than those without such conditions (M = 11.31, SD = 2.65 characters copied per min) at $p < .001$; whereas, the differences in all other domains were non-significant. The comparisons of various outcomes between these two groups are summarized in Table 3.

-- Insert Table 3 about here.--

3.3. Factors associated with writing to dictation and handwriting performance

The associations between the multiple variables were tested after the screening of outliers. The standardized values showed that there were no data points lying beyond 3.29 *SD*s from either side of the means of each of these variables, which suggested that there were no outliers from the sample (Field, 2009). However, because some of these variables were positively skewed ($Z_{skewness} > 1.96$), these variables were log-transformed (see specific note in Table 4) to improve the normality of data distribution (Field, 2009). The assumptions of normality were fairly met after the transformations.

The associations between the various outcomes measures are summarized in Table 4.

The results showed that among the children with dyslexia, their performances in writing to dictation were positively associated with average handwriting speed (*r* = .33) and character naming (*r* = .37), but negatively associated with variability of character size (*r* = -.37) and number of reading errors during rapid saccadic movement in the horizontal subtest of the DEM test (*r* = -.30). A negative association was found between the average handwriting speed and the pause time to on-paper time ratio (*r* = -.45), variability of character size (*r* = -.30), RAN (*r* = -.50), number of reading errors during rapid saccade (*r* = -.36), and saccadic efficiency (*r* = -.31). Both the mean writing pressures and variability of writing pressures were negatively associated with visual-perceptual skills, fine manual control, VMI, and saccadic efficiency (*r* = -.43 to -.32). The number of characters written exceeded grid was positively associated with average character size (*r* = .76) and variability of character size (*r* = .63), but negatively associated with VMI (*r* = -.35) and saccadic efficiency (*r* = -38). Both average character size and variability of character size were negatively associated with VMI (*r* = -.33 and -.46, respectively), and these two variables of handwriting product were highly correlated (*r* = .60).

-- Please insert Table 4 about here --

The variables that were significantly correlated with word dictation and the variables of handwriting were entered into a series of stepwise multiple regression models with adjustments of covariates (see Models A to G in Table 5). Model A indicated that among these children, their word dictation performances were significantly predicted by their character naming abilities (β = .32; ΔR^2 = .10) but not other variables in handwriting. Model B showed that their average handwriting speed was significantly predicted by their RAN abilities (β = -.36; ΔR^2 = .11) and saccadic efficiency (β = -.29; ΔR^2 = .07). The latter also significantly accounted for the variances in pause time to on-paper time ratio (β = .48; ΔR^2 = .18) in the handwriting process, as indicated in Model C. Models D and E suggested that the children with better fine manual control applied a lower average writing pressure (β = -.45; ΔR^2 = .17), with lower variability of writing pressure (β = -.45; ΔR^2 = .17) in the handwriting process. Models F and G showed that the children with weaker VMI ability produced more characters exceeded grid (β = -.41; ΔR^2 = .14), with more variability of character size (β = -.37; ΔR^2 = .12) in their handwriting product. Each of these regression models significantly explained 13.1 to 49.3% of the variances of the dependent variables. The examinations of residual plots and normal probability plots found that all of these regression models satisfied the assumptions of normality and linearity, and the co-linearity diagnostics indicated no problems in multicollinearity.

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4. Discussion

The findings from this study have enhanced our understanding of the writing difficulties among children with dyslexia in the Chinese population. It was found that over 60% of these children had profound difficulties in word dictation, and about 10% had deficits in handwriting speed and lacked legibility in handwriting. This study also replicated the findings from previous studies that reported a predominance of RAN deficit (e.g., Ho et al., 2004) and a general weakness in fine motor development among children with dyslexia (e.g., Chaix et al., 2007). Additionally, it was found that the children with dyslexia and co-morbid attention deficits and/or fine motor clumsiness experienced more difficulties in handwriting speed. This finding aligned well with the previous studies on Chinese children with ADHD (e.g., Shen, Lee, & Chen, 2012) and DCD (e.g., Chang & Yu, 2010) regarding their prolonged time in performing copying tasks. By using adjusted multivariate analyses, it was found that their overall difficulties in performing Chinese word dictation tasks were mainly contributed by their poor lexical knowledge of Chinese characters, while their difficulties in performing copying tasks were mainly associated with RAN deficits and individual differences in saccadic efficiency and VMI ability. These various factors associated with Chinese writing to dictation and handwriting performances are summarized below.

4.1. Factors associated with Chinese writing to dictation performance

It was found that the degree of difficulties in performing Chinese word dictation was associated with individual differences in recognizing Chinese characters, and co-varied with handwriting speed and character size variability. Above all, the lexical knowledge of Chinese characters contributed mostly to individual differences in word dictation performances. In the

Chinese writing system, characters are the basic morphological units that combine together to form multi-character words (Shu, 2003). Single characters usually convey multiple meanings depending on the word contexts. Therefore, the ability to recognize individual Chinese characters generally reflects their knowledge of these basic morphemes including their associated word meanings. Inabilities to recognize these characters may indicate a confusion of written characters in the long-term memory system, especially for those characters that are visually similar (e.g., 已 ji5 and 己 gei2) and those that are homophones (e.g., 興 hing1 and 輕 hing1), as suggested by Han et al. (2012). Chinese children with dyslexia may fail to retrieve the orthographic forms of the written characters that match the sounds and meanings of the target lexical words in the mental lexicon during the writing to dictation tasks. They may benefit from a pedagogical approach that gives emphasis on morphological awareness training (e.g., differentiating homophones) and illustration of basic orthographic rules. This approach was recommended for teaching young children who lack sufficient knowledge of the Chinese character morphology and the basic orthographic rules of the Chinese writing system (Packard et al., 2006; Wu et al., 2009).

4.2. Factors associated with handwriting process

This study also found that the Chinese children with dyslexia were generally slower in performing handwriting tasks that involved timed copying of familiar Chinese characters, and their handwriting speed was significantly predicted by their individual differences in saccadic efficiency and RAN ability. Since all of the selected characters used in CHAT are familiar Chinese characters to developing children (Lam et al., 2011), and the children in this study had a relatively high accuracy (80%) in reading this type of characters, it was not likely that their prolonged writing time in copying such familiar characters was related to their inability to recognize these characters. Instead, it was more likely that these children did not have a concrete representation of the various logo-graphemes and their positional regularities in these Chinese characters. This prolonged their pause time during copying, as they had to repeatedly read the internal structures of these characters in order to copy the characters accurately. This explained why the horizontal time to vertical time ratio (indication of saccadic efficiency) in the DEM test was highly predictive of the pause time to on-paper time ratio during the handwriting process in this study. This indicated that these children might rely on saccadic movement when performing the character copying tasks. This explanation is also consistent with the clinical observation that Chinese children with dyslexia had to trace back the lines of the copy template more often than typically developing children, and generally spent more time cognitively processing the internal structures of the Chinese characters (Lam et al., 2011).

More importantly, we found that the degree of RAN deficit, which was a core cognitive deficit in Chinese children with dyslexia (Ho et al., 2004), associated strongly with handwriting speed. This finding probably showed that the inability to sustain phonological information (e.g., the list of character names) in the phonological loop of the working memory system would contribute to a slow handwriting speed among the children with dyslexia (as suggested by Berninger et al., 2008). Alternatively, the finding may indicate that the Chinese children with dyslexia might have particular difficulties in sustaining the distinct visual-orthographic forms of the various logo-graphemes of Chinese characters in their graphemic buffer (Rapp & Caramazza, 1997). Accordingly, this graphemic buffer is a working memory component that is responsible for temporarily storing the graphemes of a written word before the graphemes are produced by the mechanical process of handwriting (Rapp & Caramazza, 1997). The impairment of this graphemic buffer might lead to frequent substitution errors of the logo-graphemes that share similar visual or motoric attributes within the Chinese writing system (Han, Zhang, Shu, & Bi, 2007). This might prolong the copying time of children with dyslexia, as they generally spend more time processing the logo-graphemes of Chinese characters for the sake of avoiding such errors in handwriting (Lam et al., 2011).

Interestingly, we also found that the handwriting process among the participating children with better fine manual control, which reflected a more precise control of finger and hand movement (Bruininks & Bruininks, 2005), were characterized by a lower average pen pressure and lower degree of its variability exerted on the writing surface. This probably showed that the children with better fine manual control were better handwriters in terms of their kinesthetic and proprioceptive control of the pen stem (Tseng & Cermak, 1993). In this way, those children with better fine manual control might be more capable of using a consistent force while gripping a pen to write, and more appropriately adjust for the optimal force exerted on the paper in order to produce legible handwriting (Lam et al., 2011). Nevertheless, we could not provide satisfactory explanation for the observed values of a lower range of average writing pressure and its variability among the children with dyslexia in this study. In fact, the data obtained for the writing pressure were quite different from the ones obtained from a larger sample of children with dyslexia and normal school children studying in the third grade (Lam et al., 2011). The values were however closer to the ones obtained from two other experimental studies in normal school children and adolescents (Li-Tsang et al., 2011; 2012). This result needs to be verified in future studies.

4.3. Factors associated with handwriting product

Lastly, it was found that those who were immature in VMI might manifest poor legibility in handwriting, as indicated by the number of characters exceeding grid and the greater variability of character size. This was consistent with previous studies that showed that VMI is a crucial factor affecting the legibility of Chinese handwriting (Cheung, 2007; Tseng & Murray, 1994). However, the association between VMI and handwriting speed was not found in this study. This might be due to the differences in subject sampling, as well as the differences in instruments used in the previous studies (e.g., Cheung, 2007; Tseng &

Chow, 2000).

4.4. Limitations and suggestion for future studies

First of all, this study was limited by its cross-sectional design and clustered sampling method that impeded the generalization of its findings to the Chinese school population with dyslexia. Secondly, this study failed to recruit a sufficient sample for conducting reliable analyses. The relationships between variables should be tested in prospective studies and examined in a larger sample that satisfies the minimum sample size for regression models (e.g., including at least 10 observations for each independent variable; Field, 2009). Thirdly, the between-group comparison would be more appropriate if it were made between children with dyslexia and age-matched controls instead of using the established normative data. The current study failed to recruit age-matched controls because of time constraint and difficulty to recruit children without developmental disabilities from the same study setting. Thirdly, the accuracy of handwriting and various handwriting product errors (e.g., missing or additional stroke errors) should be thoroughly analyzed in future studies. This study failed to report these data because it used an earlier version of CHAT which could not capture these data from its computer algorithm. However, all other measures were matched with its latest version.

5. Conclusion

The results of this study indicated that over 60% of Chinese children with dyslexia were functionally impaired in performing writing to dictation, and about 10% of them may have additional impairment in performing timed copying tasks marked by slowness in handwriting. The former was predicted by deficits in lexical knowledge, while the latter was predicted by deficits in RAN. Immature development of VMI and fine manual control could partly explain poor legibility in handwriting. These results provided preliminary support to a multi-stage working memory model of Chinese word dictation and handwriting. Moreover, the findings from this study imply that the intervention programs for Chinese children with dyslexia should address their fundamental deficits in lexical knowledge. This can be developed through enhancing their morphological and orthographic awareness of the Chinese writing system. On the other hand, children who present with slow handwriting speed, in particular for those children with attention deficits, might benefit from intervention programs that strengthen their attention span in retaining the visual-orthographic information in the working memory system. For those children who have illegible handwriting, therapists and clinical practitioners may utilize a bottom-up approach to strengthen their perceptual-motor skills such as VMI and fine manual control. Future research should explore the temporal relationships between these study variables and develop intervention programs to ameliorate or compensate their performance deficits.

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Figure caption

Figure 1. A brief comparison between (a) writing English words on a horizontal grid lines; and (b) writing Chinese characters within the boundary of the square grid.

Figure
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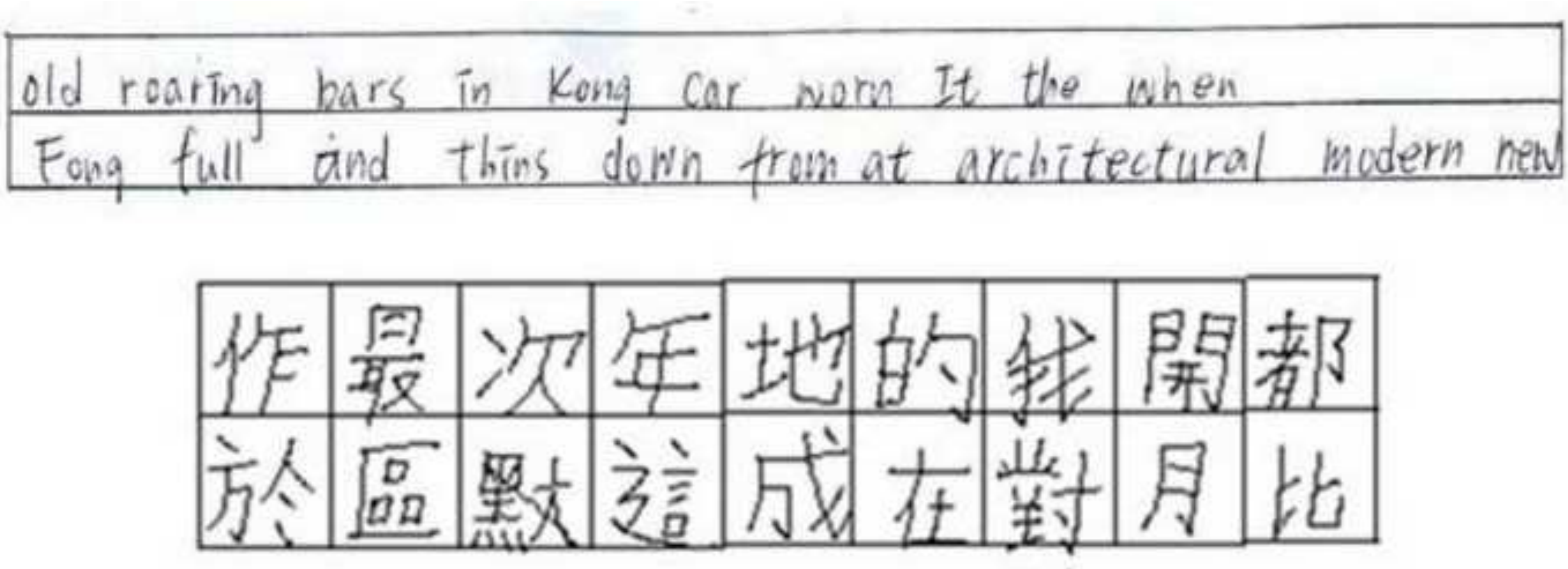

Table 1

Table 1

Demographic Information of Participants (N=45)

Variable		*M* (*SD*)	Frequency (%)
Age (Years)		9.14 (0.43)	
Gender	Male		32 (71.1)
	Female		13 (28.9)
School repeaters	First grade		2 (4.4)
	Second grade		3 (6.7)
Intellectual level[a]	Average[b]		35 (77.8)
	Above average[c]		10 (22.2)
Co-morbid developmental disorders			15 (33.3)
Diagnostic history	Attention deficits[d]		12 (26.7)
	Fine motor clumsiness[e]		4 (8.9)
Handedness	Left		3 (6.7)
	Right		42 (93.3)

Note. Information about children's intellectual level and diagnostic history were collected retrospectively from their diagnostic reports written by psychologists (for assessments of IQ and attention deficits) and occupational therapists (for assessments of fine motor clumsiness) within a two-year period.

[a]IQ test according to Hong Kong Wechsler Intelligence Scale for Children (HK-WISC; Psychological Corporation, 1981). [b]IQ = 90-119. [c]IQ ≥ 120. [d]Refers mainly to ADHD Predominantly Inattentive Type according to DSM-IV-TR criteria (American Psychiatric Association, 2000). [e]Difficulties with fine motor coordination according to clinical observations and standardized tests such as Bruininks–Oseretsky Test of Motor Proficiency-2nd edition (BOT-2; Bruininks & Bruininks, 2005).

Table_2

Table 2

Comparisons of Performances in Standardized Tests between Normative Sample and Dyslexia Sample

Variable (unit)	Possible range	Normative sample *M* (*SD*)	Dyslexia sample (*N* = 45) *M* (*SD*)	*Z*	Dyslexia sample with functional impairment (%)[a]
Writing to dictation					
Scaled score	1–19	10 (3)	3.89 (2.00)	13.66*	66.7
Raw score	0–96	NA	28.98 (11.14)		
Handwriting process					
Average handwriting speed (No. of characters copied per min)	NA	11.80 (2.68)[b]	10.39 (2.94)	3.53*	11.1
Pause time to on-paper time ratio	NA	1.75 (0.49)[b]	1.87 (0.62)	1.68	
Average writing pressure (Newton)	NA	1.11 (0.55)[b]	0.60 (0.27)	6.25*	
Variability (*SD*) of writing pressure (Newton)	NA	0.72 (0.33)[b]	0.38 (0.21)	6.89*	
Handwriting product					
No. of characters exceeded grid	NA	11.58 (13.39)[b]	18.80 (17.04)	3.62*	13.3
Average size of characters (mm)	NA	11.54 (1.65)[b]	11.91 (1.70)	1.51	
Variability (*SD*) of character size (mm)	NA	1.93 (0.40)[b]	2.55 (1.33)	10.33*	
Character naming	0–150	107.49 (16.29)[b]	76.29 (20.86)	12.85*	46.7
High-frequency characters (%)	0–100	NA	80.5 (11.9)		
Mid-frequency characters (%)	0–100	NA	45.1 (18.3)		
Low-frequency characters (%)	0–100	NA	27.3 (13.7)		
Orthographic awareness (Scaled score)	1–19	10 (3)	9.26 (1.75)	1.66	0.0
Visual perception (Standard score)	55–145	100 (15)	101.02 (12.32)[d]	0.46	0.0
Fine motor skills					
Fine manual control (Standard score)	20–80	50 (10)	44.89 (5.53)[d]	3.43*	0.0
Manual coordination (Standard score)	20–80	50 (10)	41.76 (8.54)[d]	5.53*	11.1
Visual motor integration					
Standard score	42–147	100 (15)	104.94 (14.28)[d]	2.21	0.0
Raw score	0–45	NA	20.96 (7.03)		
Developmental eye movement (DEM) test					
Vertical time (sec)	NA	36.53 (6.61)[c]	49.53 (11.73)	13.19*	35.6
Horizontal time (sec)	NA	43.03 (7.83)[c]	58.81 (17.02)	13.52*	44.4
No. of reading errors in rapid saccade	NA	2.98 (3.28)[c]	4.79 (4.35)	3.70*	17.8
Time ratio—Horizontal time/Vertical time	NA	1.18 (0.12)[c]	1.19 (0.18)	0.56	13.3

Note. NA = Not Applicable.

[a]Referred here to those children in the dyslexia sample with severe difficulties in the assessed domain (i.e., standardized score ≤ -2 *SD*s). [b]Normative data of local students in the third grade (Lam et al., 2011; Leung et al., 2008). [c]Normative data of local schoolchildren aged 9 years to 9 years 11 months (Pang, 2004). [d]Non-local norms were used for the calculation of standard scores—the ethnic groups of these normative data consisted of 65-75% White, 10-15% Hispanic, 7-15% African American, and 2-5% Asian American according to the manuals (Bruininks & Bruininks, 2005; Martin, 2006; Reynolds, 2007).

*$p < .003$ (adjusted *p*-value for multiple comparisons).

Table_3

Table 3

Comparisons of Children with or without Co-morbid Developmental Disorders

Variable (unit)	Possible range	Dyslexia only group (n = 30) *M* (*SD*)	Co-morbid group[a] (n = 15) *M* (*SD*)	$t(43)$
Age (years)	NA	9.08 (0.41)	9.25 (0.46)	-1.25
Writing to dictation (Raw score)	0–96	30.00 (10.52)	26.93 (12.42)	0.87
Handwriting process				
Average handwriting speed (characters copied per min)	NA	11.31 (2.65)	8.55 (2.70)	3.27*
Pause time to on-paper time ratio	NA	1.75 (0.38)	2.11 (0.91)	-1.45
Average writing pressure (Newton)	NA	0.64 (0.28)	0.52 (0.25)	1.41
Variability (*SD*) of writing pressure (Newton)	NA	0.40 (0.22)	0.34 (0.20)	0.91
Handwriting product				
No. of characters exceeded grid	0–90	16.20 (14.46)	24.00 (20.90)	-1.47
Average size of characters (mm)	NA	11.59 (1.48)	12.55 (1.96)	-1.84
Variability (*SD*) of character size (mm)	NA	2.25 (0.72)	3.14 (1.97)	-1.69
Character naming	0–150	74.27 (21.61)	80.33 (19.32)	-0.92
Orthographic awareness	1–19	9.17 (1.85)	9.44 (1.57)	-0.50
Visual perception	55–145	100.27 (10.99)	102.60 (14.92)	-0.59
Fine motor skills				
Fine manual control	20–80	45.70 (5.94)	43.33 (4.47)	1.36
Manual coordination	20–80	42.03 (9.05)	41.13 (7.57)	0.33
Visual motor integration (Raw score)	0–45	21.63 (6.87)	19.60 (7.39)	0.91
Developmental eye movement (DEM) test				
Vertical time (sec)	NA	47.25 (10.33)	54.08 (13.34)	-1.89
Horizontal time (sec)	NA	55.45 (15.94)	65.53 (17.66)	-1.93
No. of reading errors in rapid saccade	NA	4.77 (4.52)	4.80 (4.14)	-0.02
Time ratio—Horizontal time/Vertical time	NA	1.17 (0.15)	1.23 (0.23)	-0.92

Note. NA = Not Applicable.

[a]Referred here to those children with dyslexia and other co-morbid developmental disorders in attention deficits and/or fine motor clumsiness.

*$p < .003$ (adjusted p-value for multiple comparisons).

Table_4

Table 4

Correlation Analyses of Word Dictation and Handwriting Performance with Other Variables (Pearson's Product-Moment Correlation)

	Word dictation	Handwriting process				Handwriting product		
Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1. Word dictation	–							
2. Average handwriting speed	.33*	–						
3. Pause time to on-paper time ratio[a]	-.04	-.45**	–					
4. Average writing pressure[a]	-.11	.21	-.31*	–				
5. Variability (*SD*) of writing pressure[a]	-.14	.20	-.31*	.98**	–			
6. No. of characters exceeded grid[a]	-.27	.06	-.22	.06	.13	–		
7. Average size of characters	-.24	-.09	-.03	-.07	.01	.76**	–	
8. Variability (*SD*) of character size[a]	-.37*	-.30*	.11	.00	.05	.63**	.60**	–
9. Character naming	.37*	.10	-.06	-.16	-.11	.10	.21	-.06
10. Orthographic awareness	.13	-.09	-.03	-.11	-.11	-.03	.10	-.07
11. Visual perception skills	-.13	-.25	.27	-.43**	-.41**	-.06	.09	-.06
12. Fine manual control[a]	.21	.01	.21	-.39**	-.42**	-.19	-.19	-.28
13. Manual coordination	-.18	.16	-.01	.09	.13	.14	-.06	-.16
14. VMI	.19	.06	.17	-.32*	-.35*	-.44**	-.33*	-.46**
15. RAN (Vertical time of DEM)[a]	-.12	-.50**	.02	-.25	-.23	-.03	.12	.25
16. No. of reading errors in rapid saccade[a]	-.30*	-.36*	.29	.03	.06	.18	.12	.29
17. Saccadic efficiency (Time ratio of DEM)[a]	.02	-.31*	.40**	-.33*	-.38*	-.31*	-.28	-.00

Note. DEM = Developmental Eye Movement test (Richman & Garzia, 1987); RAN = Rapid Automatic Naming; VMI = Visual Motor Integration.

[a]Variables with log-transformation for the correction of positive skewness.

**p* < .05. ***p* < .01.

Table_5

Table 5

Stepwise Multiple Regression Models for Word Dictation and Handwriting Performance

Model[a]	Dependent variable	Step[b]	Independent variable	β	*t*	ΔR^2	*F* Change	*df*s
A	Word dictation	1	Covariates	–	–	.20	2.44	4, 40
		2	Character naming	.32	2.32*	.10	5.40*	1, 39
B	Handwriting speed	1	Covariates	–	–	.39	6.33**	4, 40
		2	RAN[c] (Vertical time of DEM)	-.36	-3.08**	.11	8.31**	1, 39
		3	Saccadic efficiency[c] (Time ratio of DEM)	-.29	-2.41*	.07	5.82*	1, 38
C	Pause time to on-paper time ratio[c]	1	Covariates	–	–	.05	0.49	4, 40
		2	Saccadic efficiency[c] (Time ratio of DEM)	.48	3.04**	.18	9.24**	1, 39
D	Average writing pressure[c]	1	Covariates	–	–	.10	1.09	1, 40
		2	Fine manual control[c]	-.45	-3.00**	.17	9.03**	1, 39
E	Variability (*SD*) of writing pressure[c]	1	Covariates	–	–	.07	0.79	1, 40
		2	Fine manual control[c]	-.45	-2.93**	.17	8.61**	1, 39
F	No. of characters exceeded grid[c]	1	Covariates	–	–	.10	1.12	1, 40
		2	VMI	-.41	-2.60*	.13	6.76*	1, 39
G	Variability (*SD*) of character size[c]	1	Covariates	–	–	.19	2.31	1, 40
		2	VMI	-.38	-2.57*	.12	6.63*	1, 39

Note. DEM = Developmental Eye Movement test (Richman & Garzia, 1987); VMI = Visual Motor Integration; RAN = Rapid Automatic Naming; Covariates included age, gender, IQ, and presentation of co-morbid developmental disorders.

[a]Adjusted R^2 for Models A to G = .20, .49,.13, .17, .14, .14, and .22, respectively. [b]Step 1: Covariates were entered by forced entry; Step 2 to 3: The most significant predictor was selected by the stepwise method for entering into the regression model.

[c]Variables with log-transformation for the correction of positive skewness.

*p < .05. **p < .01.