Visual-perceptual-kinesthetic inputs on influencing writing performances in children with handwriting difficulties

Linda F.L. Tse a, Kannan C. Thanapalan b, Chetwyn C.H. Chan a,*

a Applied Cognitive Neuroscience Laboratory, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
b Department of Occupational Therapy, Faculty of Health Sciences, Universiti Teknologi MARA, Puncak Alam Campus, Bandar Puncak Alam, Selangor, Malaysia

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A B S T R A C T

This study investigated the role of visual-perceptual input in writing Chinese characters among senior school-aged children who had handwriting difficulties (CHD). The participants were 27 CHD (9–11 years old) and 61 normally developed control. There were three writing conditions: copying, and dictations with or without visual feedback. The motor-free subtests of the Developmental Test of Visual Perception (DTVP-2) were conducted. The CHD group showed significantly slower mean speeds of character production and less legibility of produced characters than the control group in all writing conditions (ps < 0.001). There were significant deteriorations in legibility from copying to dictation without visual feedback. Nevertheless, the Group by Condition interaction effect was not statistically significant. Only position in space of DTVP-2 was significantly correlated with the legibility among CHD (r = −0.62, p = 0.001). Poor legibility seems to be related to the less-intact spatial representation of the characters in working memory, which can be rectified by viewing the characters during writing. Visual feedback regarding one’s own actions in writing can also improve legibility of characters among these children.

1. Introduction

Proficient handwriting is an important scholastic skill that children must acquire to meet common classroom demands (Feder & Majnemer, 2007; Volman, van Schendel, & Jongmans, 2006). This skill has also been regarded as an indicator of students’ academic achievement (Oppen, 1996). Handwriting involves complex visual-perceptual-motor processing mediating by attention, perception, memory, motor, and executive functions. These functions are synchronized and integrated at various levels to produce a word (Haas & Rees, 2010; Shams & Kim, 2010). After perceiving a word, the visual image of letters or shapes will be processed based on which of the actions involved in the writing are planned and executed (Erhardt & Meade, 2005). Other studies reveal that the integration of the visual-perceptual-motor processes demands substantial attentional function, with more intense functioning required for easy or familiar words than for complex or less familiar words (i.e., automaticity; Torrance, 2007; Tucha, Mecklinger, Walitza, & Lange, 2006). Besides attention, working memory plays an important role in writing (Hayes, 1996; Kellogg, 2004). In particular, visuospatial storage and processing
abilities are crucial to the transcription and generation of written words (Berninger, 1999; Jeffries & Everatt, 2004). Text generation is the translation of ideas into language representations in memory. Transcription is the translation of language representations into written words. It encodes letter forms and letter sequences in short-term memory to monitor and revise, and then handwritten output occurs. At the same time, working memory works in conjunction with long-term memory (Hayes & Cawdol-Nash, 1996), with representation of the word retrieved from long-term memory and maintained in working memory for effective transcription (McCutchan, 2000). By viewing how a word is produced, visual feedback provides inputs for forming a mental picture of the written word in working memory, which can guide the movements of the hand in handwriting (Hagura et al., 2007; Shams & Kim, 2010). A previous study revealed enhancement of legibility by visual strategies, which were found useful for learning new words or alleviating children’s writing difficulties (Daly, Kelley, & Krauss, 2003). The absence of visual feedback would limit the rehearsal process in maintaining a mental picture and spatial orientation in the execution of movement. The use of a mental picture to guide the movement would become less effective because of the weak linkage between visual and motor control. Thus, feedback would rely significantly on a kinesthetic sense that is insufficient to provide the necessary information for spatial orientation. It results in a decline of the word’s legibility.

Handwriting difficulty, also known as dyslexic dysgraphia, is defined as a specific learning disability in written language production that is not related to low intelligence (Hamstra-Blett & Blote, 1993). Previous studies indicated that 10–20% of school-age children, especially boys, experienced different types of handwriting difficulties (Ratzon, Efrain, & Bart, 2007; Rosenblum, Parush, & Weiss, 2003). Besides handwriting difficulty, poor legibility of characters was revealed in other developmental disabilities, such as Attention Deficit Hyperactive Disorder (ADHD; Karande et al., 2007; Racine, Majnemer, Shevell, & Snider, 2008) and developmental coordination disorders (Miller, Missiuna, Macnab, Malloy-Miller, & Polatajko, 2001; Tseng, Howe, Chuang, & Hsieh, 2007). In English writing, typical words produced by individuals with handwriting difficulty are characterized by incorrect letter formation, poor alignment, uneven size of letters, and irregular spacing between letters and words (Case-Smith, 2002; Graham, Struck, Santoro, & Berninger, 2006; Tseng & Chow, 2000). These individuals also tend to write slowly. In addition, they might present with phonological awareness problems (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008; Bishop & Snowling, 2004), as proper decoding of spoken words into sequences of smaller units of sound segments can help formulate the written words (Berninger et al., 2010; Tan, Spinks, Eden, Perfetti, & Siok, 2005). Other studies suggested that children with handwriting difficulties had poor legibility, but no speed problems in producing written words (Hamstra-Blett & Blote, 1993; Rubin & Henderson, 1982).

In contrast to the letter of the English language, the Chinese character is primarily logographic in nature, comprising radicals within a square configuration. A radical is composed of strokes. The accuracy in spatial relationships between strokes and a radical, and between radicals and a character, are the essence of written Chinese characters. The ability to maintain spatial orientations of strokes and radicals, and to produce them in a written form, is a challenge to all school-aged children (Ho, Chan, Lee, Tsang, & Luan, 2004; Lai & Leung, 2012). Deficiencies associated with handwriting difficulty in producing Chinese characters include slowness and poor legibility (Tseng & Chow, 2000). The common features attributable to poor legibility were in stroke formation (superfluous and missing strokes) and sequencing of strokes to the geometric position of the components in a character (i.e., disproportionate spacing and size among components; Tseng & Hsueh, 1997). For example, it is common for children to confuse “” (di, which means large or big) and “” (tei, which means very or rather), words that have similar features but different meanings. The grapheme-phoneme correspondence rules cannot be applied to a Chinese character as it maps onto the morpheme, or meaning (Siok & Fletcher, 2001). Instead, writing a spoken character involves phonological awareness and visual-orthographic processes, which are carried out in the working memory (Baddeley, Gathercole, & Papagno, 1998; Berninger et al., 2006). Various studies identified that both processes were problematic among children with handwriting difficulties (Chen, Dent, You, & Wu, 2009; Ho, Chan, Tsang, Lee, & Chung, 2006; Law, Wong, & Kong, 2006).

This study investigated the roles of visual feedback inputs (or feedbacks) on modulating the production of Chinese characters. The visual inputs were manipulated by using writing tasks progressing from copying to dictation with or without visual feedbacks. In the copying task, a sample character was displayed while the subject read and wrote the word. This would involve continuous visual (from the sample and written character) and kinesthetic feedbacks to be received by the participant seeing the character, spatial orientation of components within the character, and position in space of the character. In the dictation with visual feedback condition, the participant saw the sample character, which disappeared before the participant wrote it. The participant was allowed to read the character when writing. The feedbacks, if any, were from the written character. In the dictation without visual feedback condition, the participant saw the sample character, which disappeared at the time of the writing. The vision of the participant was blocked and therefore he or she did not read the character when writing. This enabled any feedbacks to be received by the subject to only come from the kinesthetic—but not the visual—sense of the written character. We anticipated that the cognitive demand to the participants for maintaining the speed and legibility would increase from the copying to dictation without visual input tasks. We also hypothesized that the participants with handwriting difficulty would perform more poorly, i.e., slower speed and lower legibility, than those in the control group. Across three writing tasks, we further hypothesized that the children with handwriting difficulty would perform at the lowest level when writing Chinese characters without visual feedback. Finally, we hypothesized that their performance on the writing tasks also would correlate with their visual perceptual abilities. These results help to gain a better understanding of the visual-perceptual-motor processes that modulate Chinese handwriting. The findings can also shed light on the design of visual perception assessments and interventions for children with handwriting difficulties.
2. Materials and methods

2.1. Participants

Two groups of children—one group of children with handwriting difficulties (CHD) and one group with proficient handwriting—were recruited from four and fifth grades (aged 9–11 years) in two mainstreaming primary schools located in public estates in Hong Kong. The group of CHD consisted of 22 boys and 5 girls with a mean age of 10.0 years (SD = 0.9), while the control group was composed of 25 boys and 36 girls with a mean of 10.0 years (SD = 0.63). All children learned traditional Chinese in school and used it as the primary language in written communication. Those with other developmental disabilities, such as Attention Deficit Hyperactive Disorder (ADHD) and Autistic Spectrum Disorder (ASD), were excluded from the study.

2.2. Instruments

2.2.1. Developmental Test of Visual Perception (2nd edition) (DTVP-2)

The second version of the Developmental Test of Visual Perception (DTVP-2) is a well-constructed and effective psychometric test that assesses visual perceptual skills according to the presence or absence of motor skills based on theories of visual perceptual development (Hammill, Pearson, & Voress, 1993). It includes eight subtests, which are divided into motor-reduced visual perception and visual-motor integration components. Only four motor-reduced subtests, including Position in Space, Figure-ground, Visual Closure, and Form Constancy were administered in the form of a test booklet in this study. In each item of a subtest, one picture was presented, and the students were requested to point out the answer based on the illustrated criteria.

2.2.2. Chinese character recognition test

Twenty words were chosen from a Primary Two Chinese language textbook that was used in a Hong Kong mainstreaming school. These words were further modified with fewer or greater strokes (i.e., pseudowords), and resulted in 40 stimuli (i.e., 20 words and 20 pseudowords) for the test.

At the beginning of each trial, a fixation “+” was first presented on a computer screen for 500 ms. Next, the stimulus (either a word or pseudoword) was presented randomly on the screen for 2 s, until a blank screen appeared. After viewing the character stimulus, the students needed to inspect the character for the pattern of the strokes and determine whether the character was a word or a pseudoword. They were instructed to provide a response as quickly as possible by pressing the “Z” key on the keyboard with the right index finger to indicate that the character was a word, and the “Z” key with the left index finger for a pseudoword. A maximum of 10 s were allowed in each trial.

2.2.3. Chinese character writing test

Twenty trials with the same set of words used in the Chinese character recognition test were carried out in three conditions, namely, copying, dictation (with visual feedback), and dictation (without visual feedback). At the beginning, a fixation “+” was presented for 500 ms, then the words would be presented and written in the following conditions.

The first was the copying condition, which acted as the time for learning the word and obtained the baseline performance. Under this condition, a character was randomly presented and reminded on the screen. Children were asked to view the character and copy it as quickly as possible within a 1.5 cm grid. They were reminded to copy the character within the perimeter of the grid. They could look at the word again to complete it if they forgot it as well.

For the dictation (with visual feedback) condition, a character was randomly presented on the screen for 2000 ms only. The participants were advised to look at the character and remember it until the character disappeared. They were encouraged to look at their handwriting when dictating the character and write as fast and legibly as possible. Finally, the only difference between the dictation without visual feedback and the dictation with visual feedback condition was that the participants were not allowed to see what they were writing during the dictation process.

Both speed and legibility during each subtest were recorded. Speed was measured by the total time taken to complete each character, starting from the first pointing onto the paper to the end of the final stroke.

The legibility of Chinese characters were evaluated by five criteria selected from the Tseng Handwriting Problem Checklist (Tseng, 1993) and the Handwriting Ability Checklist (Chu, 1997), using a three point Likert scale (0 = most legible, 2 = least legible); thus, given the scale, the higher the scores, the poorer the legibility. The five criteria are: (1) Square configuration (i.e., out of grid); (2) Number of strokes (i.e., superfluous/missing strokes); (3) Spatial relationship (i.e., incorrect position of components, poor alignment of characters); (4) Spacing and size (i.e., disproportional spacing and size between components of a character); and (5) Word formation (i.e., malformation of components). The total score of each character would range from 0 to 10.

2.3. Procedure

The Human Subjects Ethics Committee of The Hong Kong Polytechnic University warranted ethical approval. The researcher made contact with mainstreaming schools for the participants’ recruitment. Parents were requested to sign an informed consent form prior to the study.
To facilitate the implementation of the study, the students were randomly divided into two groups based on their students’ class and number in ascending order. One group was to complete the Developmental Test of Visual Perception (2nd edition; DTVP-2) in a group-testing situation first, while the other group was to complete training and testing of writing Chinese characters. The duration for both groups to complete the tasks was about 30 min. The groups then swapped to the Chinese writing or DTVP-2 testing immediately afterward.

2.4. Statistical analysis

Descriptive statistics, including means and standard deviations, were computed on the DTVP-2 test scores and handwriting performances of the two groups. Independent t-tests were used to identify possible differences between the two groups among DTVP-2 scores, word recognition speed and accuracy, and handwriting performances, in terms of both speed and legibility. In addition, repeated measures ANOVA was applied to explore whether there were differences in handwriting performances across the three conditions. Finally, stepwise regression analysis was performed to examine the predictability of DTVP-2 subscales on handwriting performances in children with handwriting difficulties.

3. Results

3.1. DTVP-2

Children in the CHD group had scores significantly lower than those in the control group on the Figure-ground (t = 2.34, p = 0.021) and Visual Closure subscales (t = 2.43, p = 0.016; Table 1). The differences on the Position in Space and Form Constancy subscales were not statistically significant.

3.2. Results of word recognition

The mean accuracy rate attained by the CHD group on the Chinese character recognition test was 84.2% (SD = 8.7), compared to 89.2% (SD = 9.3) for the control group. The CHD group had significantly lower correct responses (t = 2.79, p = 0.006) than the control group on recognizing the stroke formation of characters. However, the between-group difference in the mean time required for completing the character recognition test was not significantly different (CHD: M = 631.9 s, SD = 301.9 s; Control: M = 663.7 s, SD = 263.6 s; t = 0.55, p = 0.580).

3.3. Handwriting performance

Regardless of the writing conditions, the CHD group performed significantly slower than the control group in producing the characters (F(2,85) = 13.75, p < 0.001). The CHD group showed significantly slower mean speeds of character production than the control group in all writing conditions (copying: 40.9 s vs. 29.9 s; dictation with feedback: 38.8 s vs. 28.5 s; dictation without feedback: 37.4 s vs. 28.1 s; p < 0.001; see Fig. 1). The Group by Condition interactions were statistically insignificant (F(1.86) = 1.68, p = 0.199). To further control for the groups’ differences, the results from the two dictation conditions were normalized by those from the copying condition. The main effects of Group (t(86) = 2.05, p = 0.156) and Condition (F(1, 86) = 0.01, p = 0.922) were statistically insignificant. Between-group comparison on the speed of dictation without feedback after normalization by the speed of dictation with feedback also showed no statistically significant results (t(86) = 0.97, p = 0.335).

In general, the CHD group (Mean = 1.31) scored significantly higher (again, indicating less legible) on legibility than the control group (Mean = 0.43, F(2,86) = 51.24, p < 0.001). The same result was observed across each of the conditions, including copying (t(86) = 7.12, p < 0.001), dictation with feedback (t(86) = 7.53, p < 0.001), and dictation without feedback (t(86) = 5.66, p < 0.001). After normalization by the copying condition, the main effects of Group (t(86) = 4.18, p = 0.044)

<table>
<thead>
<tr>
<th>DTVP-2 subtests</th>
<th>CHD (n = 27)</th>
<th>Control (n = 61)</th>
<th>t-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position in space</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>10.88</td>
<td>11.20</td>
<td>1.10</td>
</tr>
<tr>
<td>SD</td>
<td>1.37</td>
<td>1.35</td>
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<tr>
<td>Figure-ground</td>
<td></td>
<td></td>
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<tr>
<td>M</td>
<td>9.67</td>
<td>10.89</td>
<td>2.34</td>
</tr>
<tr>
<td>SD</td>
<td>2.45</td>
<td>2.47</td>
<td></td>
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<tr>
<td>Visual closure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>10.48</td>
<td>12.15</td>
<td>2.43*</td>
</tr>
<tr>
<td>SD</td>
<td>4.04</td>
<td>3.06</td>
<td></td>
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<tr>
<td>Form constancy</td>
<td></td>
<td></td>
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<tr>
<td>M</td>
<td>10.78</td>
<td>10.52</td>
<td>-0.46</td>
</tr>
<tr>
<td>SD</td>
<td>2.50</td>
<td>2.70</td>
<td></td>
</tr>
</tbody>
</table>

Note: M = Mean, SD = Standard Deviation.
* Statistically significant at the 0.05 level (2-tailed).
and Condition ($F(1,86) = 103.12, p < 0.001$) on legibility were statistically significant, but their interactions were not significant ($F(1,86) = 0.001, p = 0.975$). Further normalization using the results from the dictation with feedback condition, the Group effect on legibility on the dictation without feedback condition reached a marginal significance ($t(86) = 1.81, p = 0.074$) with a moderate effect size (Cohen’s $d = 0.423, r = 0.207$). Among the CHD group, legibility of the copying condition (Mean = 1.31, SD = 0.74) was significantly lower (indicating more legible) than that of dictation with feedback (Mean = 1.64, SD = 0.91) ($t(26) = 4.74, p < 0.001$) and dictation without feedback conditions (Mean = 3.05, SD = 1.32) ($t(26) = 10.82, p < 0.001$). The differences between the two dictation conditions were also statistically significant ($t(26) = 9.13, p < 0.001$). The control group also displayed a similar pattern of deterioration of legibility across the three conditions.

3.4. Visual perceptual skills and handwriting performances among CHD group

Among the CHD group, the mean speeds on the Chinese character writing test were not significantly correlated with the scores on the DTVP-2 subscale (Table 2). In contrast, the legibility scores on the same test showed significant correlations with scores on the Position in Space subscale of DTVP-2 in both the copying ($r = -0.62, p = 0.001$) and in the two dictation conditions (with feedback: $r = -0.62, p = 0.001$; without feedback: $r = -0.53, p = 0.005$). The negative correlations indicated that the participants who scored higher on the Position in Space subscale tended to have lower legibility scores on the writing test (i.e., better legibility). Finally, stepwise multiple regressions demonstrated that scores on the Position in Space predicted 38.3% of the variance in handwriting legibility of the learning phase, and 38.7% and 28.4% in the dictation with or without feedback, respectively.

4. Discussion

The major finding of this study is that only position in space ability, as measured by DTVP-2, significantly predicted legibility of the characters written by the CHD group. This phenomenon was not observed among children in the non-CHD group. Position in space involves objects or shapes distributed in different spatial locations. Their manipulation has been shown to tap the function of the visuospatial sketchpad, a temporary storage of spatial and visual information (Goldstein, 2008). The significant correlations revealed in this study suggest that writing of the orthographic Chinese characters by CHD is likely to be mediated by this visuospatial sketchpad. This proposition is further supported by the notion that dictation demands more spatial organization than copying (Parush, Lifshitz, Yochman, & Weintraub, 2010). The ability of the position
in space among the CHD would have direct impact on the legibility of the characters produced in the dictation, but not in the copying conditions. On the other hand, Case-Smith (2002) reported increased position in space scores among children with poor handwriting after receiving occupational therapy intervention. At the same time, their handwriting legibility score also significantly improved, but not their speed.

The copying task in the Chinese character writing test involved the children viewing a character and copying it onto a small grid on a paper. This involved recognition of the character and shifted attention allocated between the displayed character and the grid on which the character was produced. In contrast, the dictation task demanded participants to generate and maintain the visual representation of the character in the visuospatial working memory. The representation of the character would serve as the template with which the hand movements controlled, executed, and produced the character on the grid. When compared with the feedback condition, dictation without visual feedback would make further demands on the visuospatial working memory and motor control via feedback from the kinesthetic sense. The CHD group consistently produced characters of poorer legibility than their non-CHD counterparts did. The legibility deteriorated from copying characters to dictation with the visual feedback, and performance was worst for copying without the visual feedback. These results concur with those revealed in other studies on writing of English or Chinese words (Hamstra-Bletz & Blote, 1993; Karlsdottir & Stefansson, 2002; Maeland, 1992; Smits-Engelsman & Van Galen, 1997; Sokk, Arntzen, & Thygiesen, 1987; Tseng & Murray, 1994). Parush et al. (2010) suggested that the representation included the spatial orientation and organization of the parts composing a word. For Chinese characters, the spatial organization refers to the orientation and location of the strokes and components of the characters, which are maintained in the visuospatial working memory. The poorer legibility of Chinese characters specifically refers to strokes that were less intact when forming the square configuration character; strokes that were scattered beyond the writing grid; instances where there was incorrect spatial organization and disproportional size/spacing of the strokes; and/or an inaccurate number of strokes. Apart from poorer position in space, poorer legibility performance was found to be related to lower ability of visuospatial working memory and executive function among the CHD (Chiappe, Hascher, & Siegel, 2000; Poblano, Valadez-Tepec, Arias, & Garcia-Pedroza, 2000; Reiter, Tucha, & Lange, 2004; Rosenblum, Aloni, & Josman, 2010). As a result, these children had weaker abilities to visualize and maintain the visuospatial relationships of the strokes that composed the character. This, in turn, hindered the coordination and execution of the hand movements in producing the characters.

The CHD showed a general slowness in producing the Chinese characters. The findings are somewhat inconsistent with studies based on writing of English words, which did not reveal differences in writing speed between children with and without handwriting difficulties (Hamstra-Bletz & Blote, 1993; Rubin & Henderson, 1982). Nevertheless, it is noteworthy that the speed of character production of the participants in both groups did not appear to decrease from the copying to dictation conditions in the Chinese character writing test. Our result concurs with Graham, Berninger, Weintraub, and Scharfer (1998), possibly suggesting that copying and dictating characters was mediated by mental processes not relating to speed. The slower speed among the children with handwriting difficulties did not seem to indicate a tradeoff for producing characters that are more legible. The slowness of character production was previously revealed to be attributable to both visual and motor abilities, including fine-motor and motor planning skills, as well as visual-motor integration and visual sequential memory (McHale & Carmak, 1992; Rubin & Henderson, 1982; Tseng & Chow, 2000; Yochman & Parush, 1998). A slower speed of character production means that the representation (and hence the spatial relationships of the parts) would need to be maintained in the working memory for a longer time. Consequently, this would hinder the legibility of the characters produced by the CHD.

5. Limitations

There are a few limitations in this study. First, the Chinese character writing test did not randomly sample Chinese characters available in an established word bank. Instead, they were selected from popular, age-relevant textbooks used in mainstream schools. The results obtained from the test may not be generalized to characters not included in the test. At the same time, the results of the test cannot be regarded as indicative of the level of achievement of the children. Future studies should test the robustness of the results with characters selected using other sampling frames. The DTVP-2 may suffer from ceiling effects for children in the non-CHD group. The restriction of range would inflate the standardized differences between the CHD and non-CHD groups, while attenuating the correlations with writing performances. Further research is needed to test these relationships by using different instruments and methods of measurement. The measurement of the speed of character writing was based on surveillance of the researcher using a stopwatch. This would inevitably generate human errors and potential biases in this variable. Future studies can employ electronic-based scoring to improve the quality of the data. Last but not least is the relatively small sample size of the CHD group, which potentially lowered the power of the analyses. Nevertheless, the moderate power revealed in the analysis suggests that the effect, if any, would not have significantly influenced our findings.

6. Conclusion

Handwriting is a complex visual-perceptual process influenced by many factors. This study revealed that visual-spatial perception and visual/kinesthetic feedbacks were important parameters contributing to the legibility of writing Chinese characters among children with handwriting difficulties. Our results suggest that clinicians may consider incorporating an
assessment of the position in space function for predicting and explaining difficulties experienced by children in writing Chinese characters. Writing of Chinese characters, when compared to its English counterpart, inevitably involves more intense spatial analysis (Tan et al., 2005) and kinesthetic control (Marquardt, Gentz, & Mai, 1999; Tan et al., 2005). When writing Chinese characters, children should be given the opportunity to couple visual feedback with the writing activity. For instance, the characters to be written are to be displayed so that children can reference them. This could reduce the load on the working memory for spatial analysis as well as enrich the feedback for kinesthetic control. Such methods can improve the legibility of the characters produced by the children.

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